Global carbon modeling using GOSAT observations

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The Greenhouse gases Observing SATellite (GOSAT) was launched on January 2009 to measure spatiotemporal variations of column carbon dioxide (CO2) and methane (CH4) concentrations from space. The GOSAT measurements provide uniform global coverage and thus show a standardized distribution and CO2 and CH4 concentrations over the globe, allowing an assessment of potential impact of climate change on the CO2 and CH4 budgets. Here we show how drought events influence CH4 emission in the Amazon region by using the GOSAT observation, as a case study to examine utilizationof of earth explore satellites for advancing our understanding of the global carbon cycle and for distinguishing emission sources from the atmospheric concentrations.The GOSAT mission can be considered as a demonstrator for discussing future missions of greenhouse gas observing satellites.

Keywords: satellite observations, global carbon budget, greenhouse gases

Current Status of GOSAT and GOSAT-2 Projects

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GOSAT (Greenhouse gases Observing Satellite) is the world's first satellite dedicated to greenhouse gas monitoring from space, and it was successfully launched on January 23, 2009. Although it has finished its nominal operation period (5 years) in January 2014 and is currently in the extended operation period, it has still been monitoring the Earth's atmosphere continuously. The data have been widely used not only for source/sink inversion of carbon dioxide and methane in global scale but also for assessing regional emission sources of the gases. The successor, GOSAT-2, will be launched in FY2017. Most of the design reviews for spacecraft, instruments, and ground data processing systems have been finished. The main sensor of GOSAT-2, Thermal And Near- infrared Sensor for carbon Observation -Fourier Transform Spectrometer (TANSO-FTS)-2 is designed based on CrIS (Cross-track Infrared Sounder) onboard NASA's Suomi NPP for gas sounding. It has a widened band in a short wavelength infrared region to detect carbon monoxide (CO). Intelligent pointing system, which is a dynamical system for targeting at selected clear sky scenes has been newly developed. It is expected that the detectability of clear sky scenes become larger twice or more compared with the current system. "GOSAT Air Pollution Watch" is being designed for rapid processing / distribution of GOSAT TANSO-Cloud and Aerosol Imager (TANSO-CAI) data for monitoring of air pollution caused mainly by particulate matters such as PM2.5 and Black Carbon (BC). Its testbed is already developed and basic performances have been demonstrated using TANSO-CAI data. Data processing algorithms in GOSAT Air Pollution Watch are based on but modified from GOSAT/GOSAT-2 algorithms for aerosol product so as to realize faster and timely data processing. Its data will be used to inform the current distribution of the polluted air. In addition, they will contribute to short term prediction of air pollution using atmospheric transport models. NIES would like to issue "Call for new GOSAT Air Pollution Watch partners" to extend the coverage of the testbed to Southeastern and South Asian countries. These activities may have close relationships to JCM (Joint Crediting Mechanism) activities between Japan and Asian countries.

Keywords: GOSAT, Carbon dioxide, Methane, GOSAT Air Pollution Watch

Measuring Atmospheric Carbon Dioxide with the NASA Orbiting Carbon Observatory-2 (OCO-2)

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The NASA Orbiting Carbon Observatory-2 (OCO-2) was successfully launched from Vandenberg Air Force Base in California on 2 July 2014. Two months later, its spectrometers began routinely returning almost one million soundings over the sunlit hemisphere each day. About 10% of these soundings are sufficiently cloud free to yield full-column estimates of the column-averaged CO_2 dry air mole fraction, X_{CO2}. Nadir soundings over land yield X_{CO2} estimates with single-sounding random errors that increase from 0.5 ppm to 1 ppm between the sub-solar latitude and solar zenith angles near 60 degrees. Observations of the glint spot over the ocean yield X_{CO2} estimates with single sounding random errors near 0.5 ppm at solar zenith angles below 70 degrees. The initial observing strategy recorded only glint or nadir observations over the entire sunlit hemisphere for a complete, 16-day, ground-track repeat cycle, and then used the other observing mode in the next 16-day cycle. This approach provided adequate coverage of oceans and continents on monthly time scales, but produced 16-day long gaps in the coverage of the ocean while in nadir mode, and limited coverage of high latitude continents while in glint mode. In early July of 2015, this observation strategy was modified to alternate between glint and nadir observations on alternate orbits to yield more continuous coverage of the entire sunlit hemisphere every day.
Preliminary, global maps of X_{CO2} compiled from soundings collected over 16-day ground track repeat cycles reveal some of the most robust features of the annual atmospheric carbon cycle. Regions of enhanced X_{CO2} that are co-located with intense fossil fuel emission sources in the eastern US and eastern China were most obvious in the fall and early winter of 2014, when the north-south gradient in X_{CO2} was small. X_{CO2} enhancements coincident with intense biomass burning in the Amazon, central Africa, and the Indonesian Archipelago were also most obvious during this season. In the early spring, when the pole-to-pole gradients in X_{CO2} are largest, contributions from these emission sources were clearly seen in individual orbit tracks but were much less obvious in the global maps. However, between late May and early July of 2015, OCO-2 maps show a 2-3% reduction in X_{CO2} across much of the northern hemisphere, as the land biosphere rapidly absorbs CO_2 through photosynthesis. As the carbon cycle science community continues to analyze these OCO-2 data, quantitative estimates of regional-scale emission sources and natural sinks (absorbers) are expected to emerge.
The OCO-2 team started delivering Version 7 products to the Goddard Earth Sciences Data and Information Services Center (GES-DISC) in early June 2015. These products include calibrated, spectral radiances (Level 1 products), and retrieved geophysical quantities, including spatially resolved estimates of XCO2, surface pressure, and solar-induced chlorophyll fluorescence (Level 2 products). The calibration of the Level 1 products continues to be refined, and the effort to cross calibrate these products with those from the Japanese Greenhouse gases Observing SATellite (GOSAT) are under way. The Level 2 products are currently being validated against observations from the Total Carbon Column Observing Network (TCCON) and other standards to identify and correct biases. This presentation will summarize these and other aspects of the OCO-2 mission status, early products, and near-term plans.

Keywords: carbon dioxide, carbon cycle, remote sensing

Regional methane emission estimation based on observed atmospheric concentrations (2002–2012)

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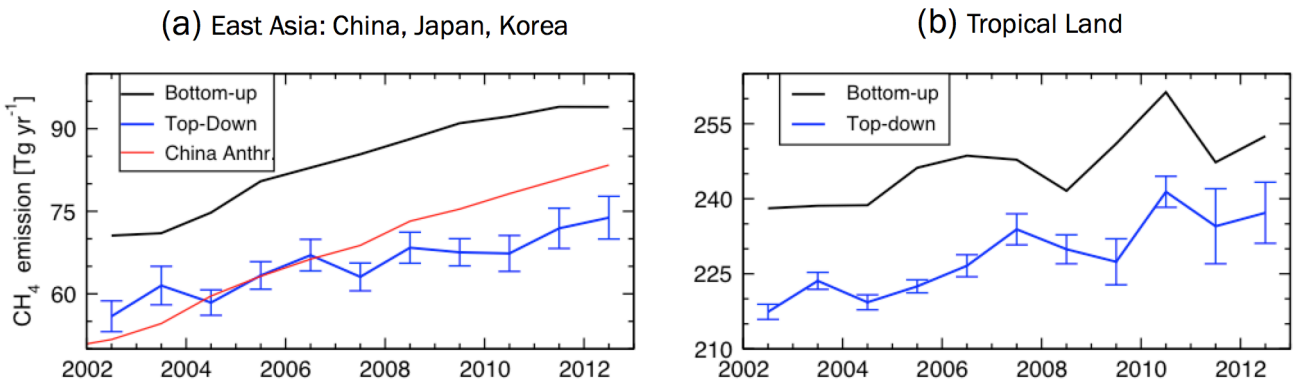
Methane (CH_4) is one of the most important short-lived climate forcers (SLCFs) due to its dual roles as a strong greenhouse gas and in air pollution chemistry. A better understanding of the regional (country-level) emissions is required for effective policymaking for emission mitigation as well as for evaluating progress of the committed INDCs (Intended Nationally Determined Contribution) at the Conference of the Parties (COP21) in Paris in 2015. An atmospheric chemistry-transport model (i.e., JAMSTEC's ACTM) has been developed to simulate greenhouse gases and ozone depleting substances. With atmospheric CH_4 lifetime being ~10 years, accurate knowledge of the transport and chemistry are established first for monitoring and verification of CH_4 emissions using atmospheric data by inverse modeling (referred to as top-down method). We have performed an ensemble of 7 inversions, by varying the bottom-up emissions for top-down estimation of CH_4 emissions from 53 partitions of global land using the ACTM forward simulations and atmospheric measurements at 39 surface sites. Our top-down results show that CH_4 emissions for the East Asian and Tropical regions are overestimated, up to about 20 Tg/yr (1Tg = 10^{12}g) each, by the bottom-up method. In contrast, top-down estimation for the southern extratropics is about 10 Tg/yr higher CH_4 emissions compared to the bottom-up method. Furthermore, the emission increase between 2002 and 2012 is also overestimated by the bottom-up method for East Asia. We use additional observational evidences to show that CH_4 emissions from coal burning is overestimated from the East Asia (China) region, and the emissions from enteric fermentation (livestock farming) is increasing in the tropical countries. We determine the tropical CH_4 emissions increase is due to livestock farming, based on an analysis of observed carbon isotopes of CH_4 ($\delta^{13}C$) by Tohoku University and animal population from Food and agriculture organization (FAO) statistics.
This study has been carried out as part of Grant-in-Aid for Scientific Research (A) (Research Number: 22241008), Suishin-hi (Research Number: 2-1401), and the Japan Society for the Promotion of Science and Arctic Climate Change Research, Green Network of Excellence (GRENE) Project (led by National Institute of Polar Research) by Ministry of Education, Culture, Sports, Science and Technology.

Keywords: greenhouse gases, source/sink inversion, regional CH4 emission



Toward assimilation of CONTRAIL data to estimate surface CO_2 fluxes

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Inverse modeling is a powerful method to elucidate carbon dioxide (CO_2) fluxes at the earth surface. Using the Bayesian algorithm, an inverse model quantitatively estimates spatiotemporal variations of surface fluxes from observations of atmospheric concentrations with help of a priori information. In this study, we have developed a new inversion system based on a state-of-the-art assimilation technique of the four-dimensional variational (4D-Var) method. Differently from a conventional method, the 4D-Var method has no limitation in the number of observations and it has an ability to estimate model grid resolution fluxes, so that regionally limited CO_2 flux anomalies such as biomass burnings are detectable. Since 2005, the aircraft measurement program named CONTRAIL has observed atmospheric CO_2 concentrations worldwide. Using the developed 4D-Var system, it is expected that such numerous aircraft data could strongly constrain the surface flux estimation especially for Asian regions. In this study, we discuss appropriate data processing or assimilation technique which is required before using the aircraft data in the flux estimation. Furthermore, we present conceivable impacts and valuable information provided by CONTRAIL for estimating Asian carbon budgets.

Keywords: carbon cycle, data assimilation, aircraft observation

Fine-scale CO_2 variations over the Tokyo megacity observed by CONTRAIL

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Urban areas are considered to account for ~70% of the global anthropogenic carbon emissions. Many cities now take actions to reduce their carbon emissions. However, atmospheric CO_2 measurement networks capable of verifying carbon emissions from large cities are still far from sufficient. CONTRAIL, an ongoing project to measure trace gases with instruments onboard aircraft of Japan Airlines, has obtained millions of CO_2 data over worldwide large cities since 2005. In general, we have observed increases of CO_2 concentration approaching down to the airports, indicating presence of CO_2 plume over metropolitan areas. We found vertical gradient of CO_2 concentration (i.e. difference between the free troposphere and the lowermost layer) larger for large megacities, suggesting that CO_2 plume correlates with size of the city. This infers that the CONTRAIL measurements may have potential to assess city's carbon emission trends. In this study, we focus on detailed analysis of CO_2 distributions over Tokyo, currently the world largest megacity. Analyzing thousands of vertical profiles of CO_2 over the Narita and Haneda airports over the last 10 years, we found CO_2 levels significantly different between areas over Haneda and north and south of Narita. This likely reflects different catchments of CO_2 plumes over the respective areas.

Keywords: Megacity, CO2, Aircraft measurements

Influence of Fossil Fuel Emissions on CO_2 Flux Estimates by Atmospheric Inversions

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Top-down approaches (or atmospheric inversions), using atmospheric transport models with CO_2 observations, are an effective way to estimate regional carbon fluxes. CO_2 flux estimates by Bayesian inversions require a priori knowledge of terrestrial biosphere exchanges, oceanic fluxes, and fossil fuel and cement production (FFC) CO_2 emissions. In most inversion frameworks, global and regional FFC CO_2 emissions are assumed to be a known quantity because FFC CO_2 based on world statistics are thought to be more reliable than natural CO_2 fluxes. However different databases of FFC CO_2 emissions may have different temporal and spatial variations especially at locations where statistics are not so accurate. In this study, we use 3 datasets of FFC emissions in inversion estimations and evaluate the sensitivity of the optimized CO_2 fluxes to FFC emissions with JAMSTEC's ACTM (an AGCM-based atmospheric chemistry-transport model) for the period of 2001–2011. Interannually varying a priori FF CO_2 emissions were based on 1) CDIAC database, 2) EDGARv4.2 database, and 3) IEA database, with some modifications. Biosphere and oceanic fluxes were optimized. Except for FF emissions, other conditions were kept the same in our inverse experiments. The three a priori FF emissions showed ~5% (~0.3GtC/yr) difference in their global total emissions in the early 2000's and the difference reached ~9% (~0.9 GtC/yr) in 2010. This resulted in 0.5–1 GtC/yr (average 2001–2011) difference in the estimated global total emissions for the ACTM inversions. Regional differences in the FFC emissions were relatively large in East Asia (~0.5 GtC/yr) and Europe (~0.4 GtC/yr). These a priori flux differences caused differences in the estimated biosphere fluxes in East Asia and Europe. Boreal North America and North Africa had less difference in FFC emissions but showed larger difference in estimated fluxes which might be affected by their neighboring regions.
Forward simulation results with the prior and posterior fluxes were compared with aircraft measurements over Japan by Tohoku University to validate the flux amplitudes and trends.
Acknowledgements. This work is supported by the Environment Research and Technology Development Fund (2-1401) of the Ministry of the Environment, Japan. We thank Ingrid T. van der Laan-Luijkx for providing IEA FF emission dataset.

Keywords: Carbon cycle, CO2, Inverse modeling

Development of anthropogenic pollutant emission inventory for India and its validation using satellite data

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India is facing serious problems caused by heavy air pollution. Delhi has been ranked as the most polluted city in the world, and other 12 Indian cities have been also ranked within the top 20 polluted cities. It is urgently required to introduce effective strategies to improve air quality over India. Air pollution is caused by primary pollutants which are directly emitted by sources and secondary pollutants which are formed in the atmosphere from various precursors via complex photochemical reactions. Emission inventory which tabulates amount of emissions of primary pollutants and precursors emitted from various sources could be helpful to consider effective strategies.

This study has developed emission inventory of primary pollutants and precursors emitted from anthropogenic sources in India. The target sectors include domestic combustion, transport, industrial combustion, power plants, and non-energy sources. GAINS-Asia model were utilized to estimate CO, NOx, SOx, non-methane volatile organic compounds (NMVOCs) and particulate matter (PM) emissions based on information of emission factors, activities, and abatement technologies. Such information was collected from various reliable government and published data sources.

Estimated amount of CO, NOx, SOx, NMVOC and PM_{10} emissions in whole India is 53.8, 5.41, 7.03, 9.81, and 10.7 Tg for year 2010. The highest contributors to emissions are domestic combustion for CO and NMVOC, transport for NOx, power plants for SOx, and industrial combustion for PM_{10}.

In order to use the emission data in air quality simulations, the emissions were horizontally allocated to 36 x 36 kilometers meshes covering whole India based on district-wise information on registered vehicles and population, and state-wise information on industries. For large industries like cement, refineries, oil and gas explorations, iron and steel, thermal power plants, allocations were made at their exact location. The emissions of some sectors are vertically and temporally allocated based on information including traffic flows, time of cooking, and stack heights.

An air quality simulation using the regional chemical transport model, CMAQ version 5.0.2 were conducted to validate the emission data. The meteorological field was fed from the regional meteorology model, WRF version 3.7.1. In addition to the anthropogenic emissions developed in this study, GFED version 4.1 was used for biomass burning emissions, and MEGAN version 2.0.4 was utilized to estimated biogenic VOC emissions. The target domain consisted of 36 x 36 kilometers meshes includes several surrounding countries as well as whole India. The gridded emission database of ECLIPSE version 5a was used for the anthropogenic emissions from other surrounding countries than India. The gridded concentration fields simulated by the global chemical transport model, MOZART4 were provided as boundary concentrations.

The simulated results were compared with the satellite data. The retrieved values of aerosol optical depth (AOD) over the target domain in the MODIS level 2 dataset, and the simulated values at the corresponding locations and timings were picked up. While the simulation well reproduced features in a horizontal distribution of AOD indicating high aerosol loading over the Indo-Gangetic plains, its absolute level was underestimated. It is much important to improve emission inventory for not only anthropogenic sources but also missing sources including fugitive dust.

Keywords: Emission inventory, Air quality simulation, Satellite data

Examination of the impact from biomass burning emissions on NO_2 column density over Southeast Asia

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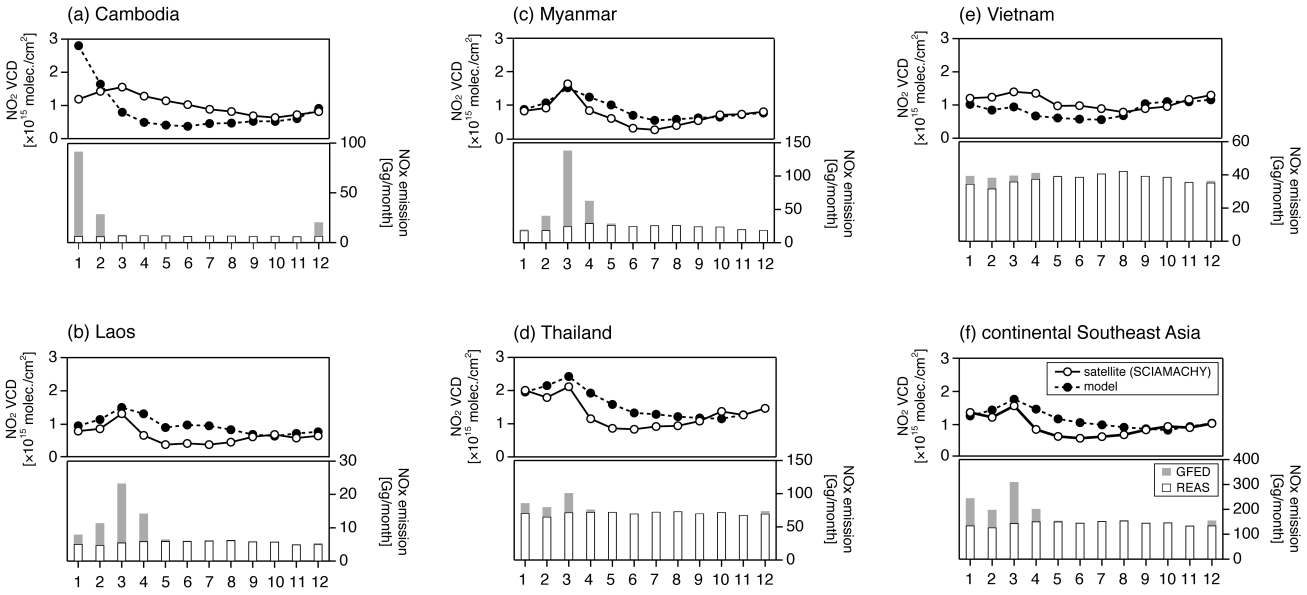
In Southeast Asian countries, the emissions originated from biomass burning is one of the concerning issue during dry season. In this study, the impact from biomass burning emissions on the tropospheric NO_2 vertical column density (VCD) over continental Southeast Asia (Cambodia, Laos, Myanmar, Thailand, and Vietnam) was systematically analyzed using satellite observations by the SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) and a regional chemical transport model (CTM) during 2003-2008. NO_2 VCD over continental Southeast Asia showed a distinctive large peak from winter (December) to early spring (April). The regional CTM was configured with anthropogenic emissions taken from the Regional Emission inventory in Asia (REAS) version 2.1 and biomass burning emissions taken from the Global Fire Emissions Database (GFED) version 3.1. Overall, the model could reproduce the NO_2 VCD observed by space-borne sensors. Mismatch between satellite observations and the regional CTM was found only in January over Cambodia. A likely reason for this mismatch was diurnal variation in biomass burning emissions. During the analysis period, the largest biomass burning event was reported from December 2003 to April 2004, and a sensitivity analysis was conducted by omitting the biomass burning emissions in the CTM. It was found that the seasonal variations of NO_2 VCD, with the peak during winter to early spring, were caused by biomass burning emissions in all countries in continental Southeast Asia. The contribution of biomass burning emissions to NO_2 VCD over continental Southeast Asia was an average of 28% during this period and a maximum of 58% in March 2004.

Keywords: Southeast Asia, Biomass burning emissions, NO2 vertical column density, Satellite observation, Regional chemical transport model



Estimation of global CO2 emission by biomass burning from 2001 to 2015

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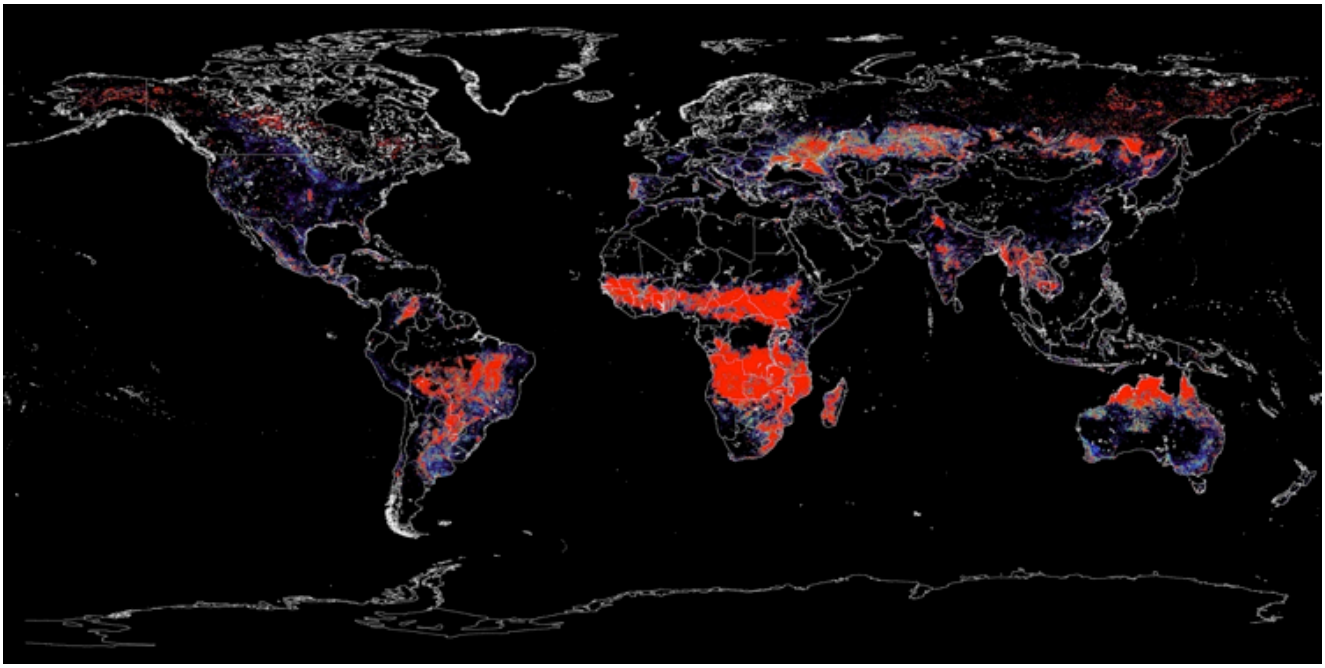
As a cause of global warming, CO2 is most effective green house gas and many countries are trying to reduce emission of that. However, the report of quantitative description is few still because the amount of CO2 emission is difficult to estimate for their complex process.This research is to devise a method to estimate the carbon dioxide (CO2) emissions from biomass burning such as forest fires and field burning in croplands in Global scale. The methodology consists of mainly three types of bio-physical parameters including (1) fire hotspots and radiative power measurements by MODIS thermal anomalies, (2) above ground biomass changes calibrated by MODIS NDVI and LAI indices, (3) ground water table modeled by MTSAT thermal anomalies and GSMaP rainfall measurements. Field campaigns were carried out from 2012 April to September in four types of land covers in (1) mangrove forest in Thailand and Vietnam (2) grassland in Mongolia (3) rice paddy field in Indonesia and Thailand and (4) forested peatland in Indonesia. Above ground biomass mapping of mangrove forest was investigated by ALOS PALSAR HH and HV polarimetric backscatter coefficients and an allometric equations derived by in-situ measurement of biomass parameters. That of grassland in Mongolia was mapped by MODIS LAI and NDVI, grassland height by ICESaT GLAS supplemented by in-situ observations. Rice paddy fields cropping patterns were mapped by MODIS NDVI and AMSR-E land surface water coverage parameters. Ground water table (GWT) was mapped to represent dryness over forested peatlands and the number of peat fires and peat decomposition were modeled with satellite-derived GWT and that of in-situ measurement. The estimated CO2 emissions from 2001 to 2015 were demonstrated and compared with Global Fire Emission Database version 4 (GFED 4) and EDGAR global database, and discrepancy between the models, challenges and technical problems were also discussed.

Keywords: land cover change, wild fires, emission inventory



Data-driven synthesis on terrestrial CO_2 budget changes in Asia

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Observational data provides a good constraint on understanding terrestrial CO_2 budget in a quantitative way. In recent years, more and more observation data (both satellite and ground observation) are being available, therefore, effective use of these data is an important step to improve our understandings of terrestrial CO_2 budget. In this presentation, we will show our recent progresses on the data-driven synthesis of terrestrial CO_2 budget in Asia. Topic includes (a) data-driven terrestrial CO_2 budget comparison in Asia as a continental scale case, and (b) satellite data analysis of large fire events in Southeast Asia in 2015 as a regional scale case.
The first part synthesizes results of data-driven top-down and bottom-up estimations of terrestrial CO_2 budget in Asia. We used an empirically upscaled estimation of terrestrial CO_2 budget using AsiaFlux data and remote sensing data (bottom-up approach) and GOSAT Level 4A product (top-down approach). The differences of the two estimation were explained by different definition of them in Siberia and East Asia. The empirically upscaled estimation is 'net ecosystem productivity', which is a difference of gross primary production and ecosystem respiration, and GOSAT L4A is land-atmosphere net CO_2 fluxes, which includes fire, dissolved inorganic carbon export through river, and land use changes. The Southeast Asia region shows large differences between the two estimations, implying the requirement of further research.
The second part focuses on analysis of forest fire in Southeast Asia. In 2015, an intense El Nino occurred, resulting in extremely low rainfall, anomalous fire were reported in Indonesia and countries in the tropical Asia. Using multiple satellite-based data, such as aerosol optical index, land surface temperature, active fire counts, and vegetation index, the large scale massive fire event in 2015 were analyzed. We clearly detected anomalous climate and fire occurrence in Southeast Asia during August to October from MODIS active fire counts, and aerosol optical index. These data shows strong anomalous patterns compared with the normal year. We analyzed the cause of more frequent fire events in El Nino years, and found that persistent negative anomalies in precipitation is most strongly correlated with fire frequency at interannual time scales.
Acknowledgement
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Keywords: Material Cycle, Asia, Fire, Terrestrial Biosphere

Network connection of tower flux measurement data :Toward long term stable flux measurement

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Since last half of 1990's, many flux towers have been constructed mainly for monitoring CO_2 flux using eddy covariance method at various land ecosystems in the world. And much effort have been made to keep data quality. Comparing with standard environmental factors (e.g. sun radiation, wind speed), eddy covariance measurement requires sensitive equipment (infrared CO_2 gas analyzer and supersonic anemometer), frequent maintenance and severe data quality are necessary. On the other hand, to evaluate the effect of land ecosystem to global climate change, long term and quality certified data are demanded. We, 4 national research institutes, constructed and have maintained 11 CO_2 flux measurement towers in Japan and East Asia (Fig.1, 8 in Japan and 3 in East Asia countries). To reduce effort of maintenance and increase data quality, we have conducted following contrivances supported by Environmental Agency Fund.
1. For quick check of flux measurement devices and data quality, we constructed the system to integrate whole flux site data in a data saver at Tsukuba using network.
2. To reduce effort of data analysis, we set up standardized flux data format and developed an automated flux data analyze system.
3. To check each site data quality, we developed a mobile closed pass CO_2 flux measurement system
4. For quick learning of flux measurement technique, we published a flux measurement manual (http://www2.ffpri.affrc.go.jp/labs/flux/manual/FluxManual_Ver1.1b.pdf)

Keywords: CO2 flux, Land ecosystem, Flux tower

Fig.1 11 tower flux sites in Asia

