GOSAT and OCO-2: New tools for studying interactions between the carbon cycle and climate

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Space based remote sensing is now providing new tools for studying atmospheric carbon dioxide (CO_2) and the interactions between the global carbon cycle and climate. The Japanese Greenhouse gases Observing SATellite, GOSAT, has been operating since 2009, collecting up to a thousand high-spectral-resolution measurements of reflected sunlight in cloud-free skies each day. These spectra are analyzed with remote sensing retrieval algorithms to estimate the column-averaged dry air mole fractions of CO_2 (X_{CO2}) and CH_4 (X_{CH4}) with single-sounding precisions and regional scale biases < 0.5% (~2 ppm X_{CO2}, ~10 ppb X_{CH4}). In July of 2014, the NASA Orbiting Carbon Observatory-2 (OCO-2) joined GOSAT and is now returning around 100,000 X_{CO2} estimates over the sunlit hemisphere each day. OCO-2 X_{CO2} estimates have single sounding random errors near 0.5 ppm (0.125%), and biases typically < 1 ppm.

The OCO-2 team retrieved X_{CO2} and solar induced chlorophyll fluorescence (SIF) from the first 7 years of the GOSAT V201 product using the same retrieval algorithm used to generate the OCO-2 Version 7 (v7) product. The carbon cycle science community is now using this combined GOSAT/OCO-2 science data record to study the response of the carbon cycle to the strong 2015-2016 El Niño. By comparing OCO-2 observations to a climatology compiled using earlier GOSAT data, Chatterjee et al. (2017) find an X_{CO2} reduction of 0.5 ppm in the central equatorial Pacific Ocean (Nino 3.4 region) between March and July of 2015, consistent with a reduction in ocean outgassing associated with El Niño. However, in August 2015, while D*p*CO_2 measurements from a TAO/TRITON buoy in the Nino 3.4 region still showed suppressed CO_2 outgassing at that location, OCO-2 observations over the equatorial Pacific showed enhanced X_{CO2}. Chatterjee et al. attribute this change to a combination of biomass burning and general reduction in vegetation uptake over tropical continents.

To test this further and assess the relative roles of drought, temperature stress, and fires on the Net Biospheric Exchange (NBE) during the 2015-2016 El Niño, Liu et al. (2017) used the Carbon Monitoring System (CMS-Flux) flux analysis system to analyze GOSAT and OCO-2 observations. They compared the El Niño results to a baseline NBE derived from GOSAT X_{CO2} estimates collected during the 2011 La Niña. Relative to 2011, they found enhanced CO_2 emissions throughout the tropics during the 2015-2016 El Niño, with an additional 0.91 ±0.24, 0.85 ±0.21, and 0.60 ±0.31 gigatons of carbon (GtC) from tropical South America, tropical Africa, and tropical Asia, respectively.

While these CO_2 anomalies had similar amplitudes, different processes dominated in each region. MOPITT CO data indicate that fires aided by high temperatures and drought dominated the CO_2 emissions over tropical Asia. GOSAT SIF estimates indicate increased respiration over central Africa, which had high temperatures but nearly normal rainfall, while tropical South America had reduced gross primary production (GPP) and drought. These observed changes may reflect differences in forcing or differences in prior conditions (prior natural disturbance, drought, etc.). They support the hypothesis that the high CO_2 growth rate during the 2015-2016 El Niño was primarily due to tropical land carbon fluxes, but show that the mechanisms may vary from continent to continent. This has important implications for both the predictability of carbon-climate feedbacks and future efforts to manage ecosystem carbon emissions.

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Liu, J., et al., A. Contrasting carbon cycle responses of the tropical continents to the 2015 El Niño, Science, in review, 2017.

Keywords: Orbiting Carbon Observatory-2 (OCO-2), Greenhouse gases Observing SATellite (GOSAT), carbon dioxide, global carbon cycle

Estimating local GHG emission amount using GOSAT

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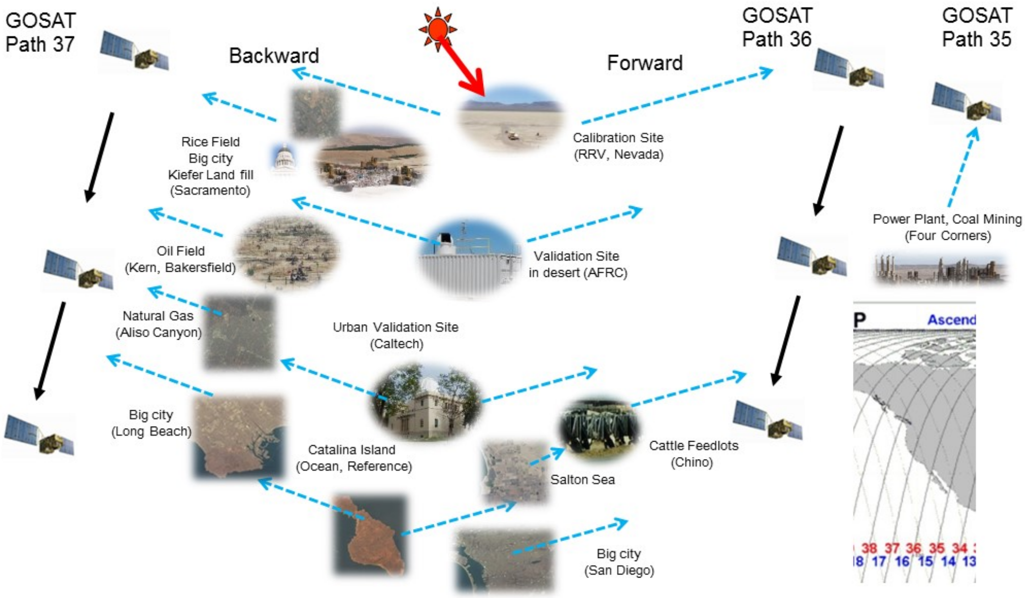
High spectral resolution spectrometers such as the Greenhouse gases Observing SATellite (GOSAT) have successfully retrieved column-averaged dry air mole fractions of CO_2 and CH_4 globally with an accuracy of 2 ppm or 0.5% and 13 ppb or 0.7%, respectively. However, spatial coverage is sparse, and a spatial resolution of 10.5 km is not sufficiently high for detecting local greenhouse gas (GHG) enhancement. Several research groups have been trying to estimate the GHG emission amount from different sources, which are not uniformly distributed. To estimate the emission flux quantitatively from space, the satellite footprint should cover an entire emission area to the extent and wind speed information is required. Therefore, a combination of sampling pattern and frequency should be optimized. Here, we discuss the time-scale and seasonal variation of both point and area emission sources.
Using the GOSAT target observation capability with an agile pointing, we demonstrate enhanced GHG measurement associated with (1) extremely high emissions from a gas leak at the north end of the Los Angeles (LA) basin, (2) a widespread megacity and point source at the west end of the LA basin, and (3) seasonal variations in the seven-year data set.
Satellite remote sensing has high precision but usually has bias and requires appropriate proper reference points. We selected three reference points near LA: the Railroad Valley, NV (remote desert); the Armstrong Research Center (desert close to the LA basin); and Catalina Island (isolated ocean). We used the XCO_2 product of ACOS B73 and the XCO_2 and XCH_4 product of RemoteC from GOSAT level 1B V201.202
In this study, we also show the quantification limit obtained from the present GOSAT observation and propose an idea to modify the instrument suite by improving spatial resolution and spatial coverage, adding mapping capability and observing other short lived atmospheric trace species.

Keywords: GOSAT, CH4 Emission, CO2 Emisson, TANSO-FTS, Satellite, Greenhouse Gases


GOSAT
Path 37
Backward
Forward
GOSAT
Path 36
GOSAT
Path 35
Rice Field
Big city
Kiefer Land fill
(Sacramento)
Calibration Site
(RRV, Nevada)
Power Plant, Coal Mining
(Four Corners)
Oil Field
(Kern, Bakersfield)
Validation Site
in desert (AFRC)
Natural Gas
(Aliso Canyon)
Urban Validation Site
(Caltech)
Big city
(Long Beach)
Catalina Island
(Ocean, Reference)
Cattle Feedlots
(Chino)
Salton Sea
Big city
(San Diego)
P
Ascend
38 37 36 35 34
17 16 15 14 13

Monitoring anthropogenic carbon dioxide and methane emission at regional scale using GOSAT observations

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Carbon dioxide (CO_2) and methane (CH_4) are the most important greenhouse gases in terms of radiative forcing. Anthropogenic activities such as combustion of fossil fuel (for CO_2) and gas leakage, animal agriculture, rice cultivation and landfill emissions (CH_4), are considered major sources of their emission. Emission data usually depend on national emission reports, which are seldom evaluated independently. Here we present results of a statistical method of comparing anomalies in global atmospheric CO_2 and CH_4 (2009-2014) fields due to anthropogenic activities, using GOSAT observations of column-average dry air mole fractions (XCO_2 and XCH_4) with atmospheric transport model simulations using high-resolution emission inventories. The CO_2 and CH_4 concentration enhancement due to anthropogenic activities, are estimated with the transport model for all GOSAT observations using high-resolution emission inventories (ODIAC and EDGAR respectively). Based on these values, anthropogenic greenhouse gas abundance is calculated using GOSAT observations as anomalies from clean background observations. These anomalies are binned and analyzed for continental scale regions and countries. For CO_2, we have found global and regional linear relationships between model and observed anomalies especially for Eurasia and North America. The analysis for East Asian region showed a systematic bias (around 15%) that is comparable in magnitude to the reported uncertainties in emission inventories in that region. In the case of CH_4, we found a good match between inventory-based estimates and GOSAT observations for continental regions. The inventory-based estimates over North American region is biased upward (around 35%) which is in agreement with recent reports. The results indicate the potential utility of GOSAT observations in monitoring reported anthropogenic emissions over different regions of varying spatial scales.

Keywords: anthropogenic emission, greenhouse gases, emission monitoring

Lidar atmospheric column CO_2 mixing ratio estimates obtained during ACT-America flight campaigns

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The Multi-functional Fiber Laser Lidar (MFLL) instrument is an Intensity-Modulated Continuous Wave (IM-CW))Lidar designed to measure differential transmission due to CO2 and the path length between the platform and the ground from two closely spaced laser lines. This information can be used with knowledge of the atmospheric state and the absorption cross-section determine the average column dry air mixing ratio XCO2.

MFLL uses three intensity-modulated range-encoded waveform lasers. The On channel is the laser at the center of a CO2 absorption line at 1.571nm. The two Off line channels correspond the lasers at plus and minus 50pm away from the Online, named Off_long and Off_short, respectively. The received power differences between On and Off lines are mainly due to atmospheric CO2 absorption.
Thus, the power ratio of On and Off lines is used to derive the differential absorption optical depth at the CO2 absorption band.

MFLL has been flown onboard the NASA C-130 research aircraft during the first two of five planned Atmospheric Carbon and Transport America (ACT-America) campaigns in the summer of 2016 and winter 2017, along with other in situ greenhouse gas monitoring instruments.
ACT-America airborne field campaigns are focused on three regions in the eastern United States and designed to cover different seasons and weather conditions like fair weather and frontal crossings.
The planned remaining campaigns are fall 2017, summer 2018, and spring 2019. The choice of different seasons, weather conditions, and regions are to span a range of surface fluxes and atmospheric transport regimes. The XCO2 results derived from MFLL for the first two flight campaigns and their comparisons with in-situ observations obtained during ACT-America will be presented.

Keywords: Atmosphere, Lidar , CO2

Process attribution of observation-model error via time-series segmentation analysis

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Process-based carbon cycle models have been vital for understanding complex land-atmosphere feedbacks and for isolating mechanisms driving source-sink dynamics across space and time. Benchmarking these models to observational datasets has improved their usefulness and optimization of model parameters has continued to reduce uncertainty and improve confidence in predictions. However, past benchmarking and optimization efforts, while useful, have overlooked the nuance of the error structure in observation-model and model-model evaluations. For example, the phase and amplitude of seasonality of atmospheric CO_2 is often evaluated from a monthly-mean harmonic function. This makes sense if our aim is to generalize and identify major features of observation-model mismatch, yet this type of generalization reduces the error structure to single metrics and therefore overlooks subtleties that can be used to identify important mechanisms driving inter- and intra-annual variation in atmospheric CO_2. The wave-function segmentation method matches (rise and fall) segments between two curves and decomposes the error structure into a joint time-series of errors in phase and magnitude. We apply the segmentation method to a comparison between GOSAT-derived observations of column-averaged CO_2 (XCO2) (2009-2015), and carbon fluxes from the biosphere (7 processed-based carbon cycle models), fossil fuel, and ocean, which underwent forward-transport model simulation for purposes of reproducing atmospheric mixing and co-locating the simulated XCO2 to GOSAT observations; regional time-series of XCO2 (observed and modeled) first underwent standard wave-decomposition to separate the long-term and seasonal cycle and to retain short-term harmonic variability. We then demonstrate how, for each segment of the XCO2 curve, the time-series of errors in phase and magnitude can be attributed to issues in their practical representation in models. We also demonstrate how the time-series of errors can be used to inform model development by evaluating the effect of alternate models of phenology and land use change on the error structure with an objective to better mirror inter- and intra-annual variability in the observed time-series. Our approach for analysis improves observation-model and model-model evaluations by decomposing the error structure into a joint time-series of errors in phase and magnitude whilst preserving the natural asymmetries in the intra- and inter-annual variation of carbon fluxes.

What controls the seasonal cycle of columnar methane observed by GOSAT over different regions in India?

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Methane (CH_4) is the second most important anthropogenic greenhouse gas (GHG), and plays critical role in air pollution chemistry in the troposphere. With the availability of satellite observations from space, variabilities in CH_4 have been captured for most parts of the global land with major emissions. The satellite observations however do not allow us to derive emission information directly, unlike the in-situ measurements, without separating the role of transport and chemistry in the columnar dry-air mole fractions (XCH_4). Here we analyze XCH_4 variability over different regions of India, Arabian Sea and Bay of Bengal, measured by the GHGs Observation SATellite (GOSAT) using an atmospheric chemistry-transport model (ACTM). We show that the peak in observed XCH_4 over the Indo-Gangetic Plain (IGP) during the southwest (SW) monsoon season (July-September) is produced mainly from the emissions on the surface (50% in 1000-600hPa layer) and uplifted high-CH_4 air mass in the upper troposphere (30% in the 400-0 hPa layer) using the ACTM simulations. These contributions are, in contrast, generated mostly from the upper troposphere over the semi-arid western India, up to 70% from the 600-0 hPa layers. This is because the signal from high CH_4 emissions during SW monsoon season is confined to a smaller region of the IGP, while the large-scale deep convection coupled with the anticyclonic wind during the SW monsoon lead to widespread CH_4 enhancement covering the whole South Asia and extending through the East Asia.

Keywords: GOSAT, methane, South Asia

Methane emission estimate from South Asia: AMASA project

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Methane (CH_4) is the second most significant anthropogenic greenhouse gas (IPCC AR5, 2014) after carbon dioxide (CO_2). Large fraction of CH_4 emissions (~150 Tg of 550 Tg globally; 1Tg=10^{12}g) occur in the Asia region. Much of CH_4 emissions from Asia are attributable to ruminant animals and rice fields, but the quantitative estimate of those emissions remains highly uncertain. To improve CH_4 emission estimate from South Asia, we started a project "Atmospheric Methane and Agriculture in South Asia (AMASA)", which is sponsored by the Ministry of the Environment Japan. The first goal of the project is to develop high-resolution emission maps at regional scale and improve our understading of CH_4 emission distributions from South Asia by using remote sensing data of CH_4 from Japanese satellite Greenhouse Gases Observing Satellite (GOSAT), in-situ measurements at ground-based stations and atmospheric chemistry-transport model (ACTM) simulations. The second goal is to develop an emission mitigation proposal using results from India-specific rice field experiments for different management practices. Some emission mitigation scenarios will be developed based on the field data, and using the ACTM we examine to what extent the emission reductions are detectable by the measurement systems if the emission mitigation policy is realized.
GOSAT is the first satellite that is dedicated to greenhouse-gas-monitoring. The onboard Sensor TANSO-FTS (Fourier Transform Spectrometer) is designed to measure CO_2 and CH_4. GOSAT has collected data for about 8 years, and validation studies revealed sufficient reliability of GOSAT data for CH_4 cycling in the Earth's environment (e.g., Morino et al., 2011, Inoue et al., 2014, Ono et al., 2015). The essential merit of satellite observation is wide spatial coverage. We found very high concentrations of CH_4 over Asia in GOSAT data, which seem to be connected to the high CH_4 emissions from this region. However, the connection is not straightforward because of complicated transport mechanisms. In particular, at the foothills of Himalaya Mountains, upwelling wind lift the CH_4 up to mid- and upper-troposphere during the monsoon season, resulting in the high columnar concentrations that can be observed from GOSAT (Chandra et al., 2017, paper in preparation). We are also conducting field measurements of atmospheric CH_4 at ground-based stations in Karnal, Sonepat, Nainital, and Comilla. Combined use of those satellite-based and ground-based measurements can give us spatial structure of CH_4 distribution, which would improve the emission estimate using an inverse analysis system.
To develop an emission mitigation proposal, we are conducting rice field experiments at the Tamilnadu Rice Research Institute, India by managing rice cultivars, water table and soil properties. The preliminary results suggest that CH_4 emission from rice cultivation can be reduced by half when applying proper cultivation managements. Based on these new findings, we are pursuing an appropriate mitigation proposal to reduce CH_4 emissions from South Asia.

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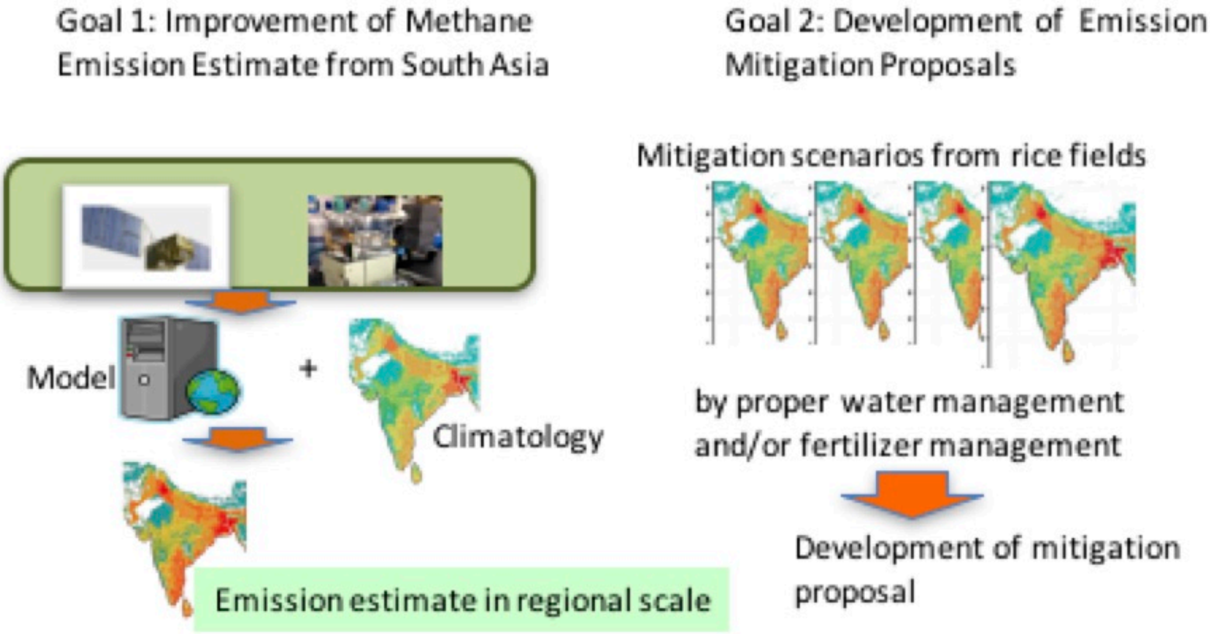
Keywords: methane, greenhose gas, Asia



Impacts of climate and reclamation on temporal variations in CH_4 emissions from different wetlands in China: From 1950 to 2010

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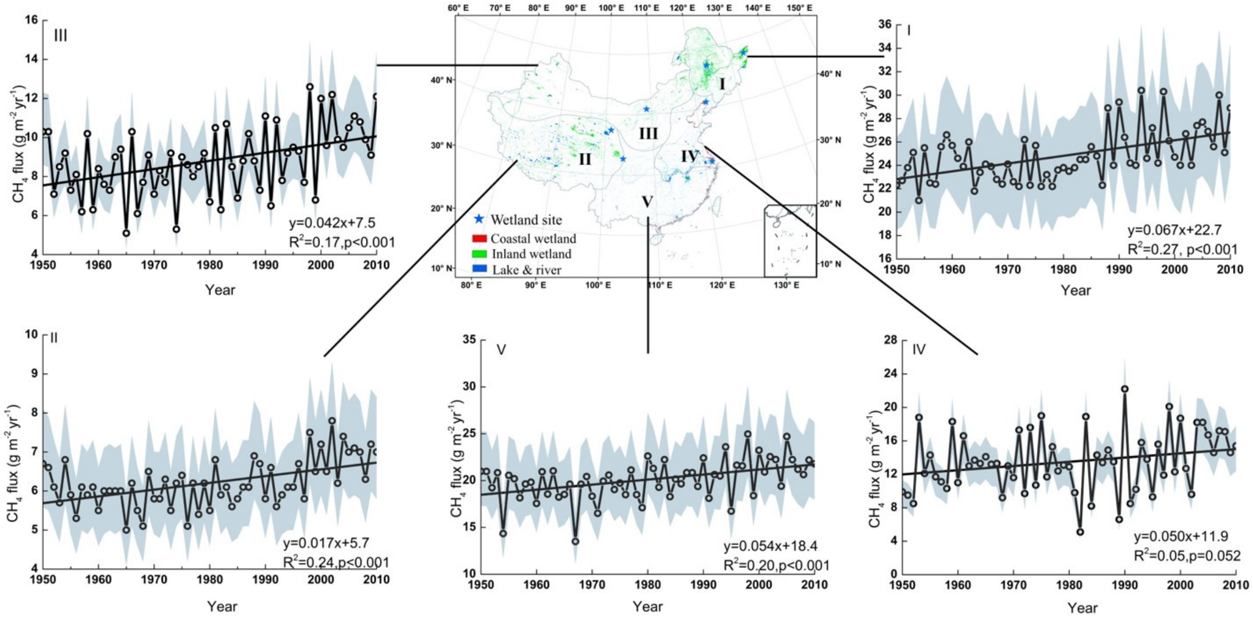
During the last 60 years, wetlands have experienced extensive conversion and global impacts from climate warming, which makes the estimation of methane emission from wetlands highly uncertain. In this paper, we present a modeling framework, integrating $CH4MOD_{wetland}$, TOPMODEL and TEM models, to analyze the temporal and spatial variations in CH_4 emissions from natural wetlands (including inland marshes/swamps, coastal wetlands, lakes and rivers) in China. We firstly evaluated the performance of the $CH4MOD_{wetland}$ model in simulating CH_4 emissions from 11 representative wetland sites in five regions of China. Model performance analysis showed that this method effectively simulates differences in the CH_4 fluxes between different sites and regions. The model efficiency for estimating the daily CH_4 fluxes in the northeastern China (NE), Inner Mongolia and northwestern China (NW), the North China plain and the Middle-Lower Yangtze Plain (E) and the Qinghai Tibetan Plateau (SW) was 0.51, 0.20, 0.52 and 0.65, respectively. The efficiency for estimating the annual mean CH_4 fluxes in southern China (S) was 0.99. On a national scale, our analysis revealed an increase of 25.5%, averaging 0.52 g m^{-2} per decade, in national CH_4 fluxes from 1950 to 2010 in Chinese wetland, which was mainly induced by climate warming. Higher rates of increasing CH_4 fluxes occurred in NE, NW regions, associated with large temperature increases. However, decreases in precipitation due to climate warming offset the increase in CH_4 fluxes in these regions. The CH_4 fluxes from the wetland on the SW region exhibited a lower rate of increase, which was approximately 25% of that simulated in NE region. Although climate warming has accelerated CH_4 fluxes, the total amount of national CH_4 emissions decreased by approximately 2.35 Tg (1.91–2.81 Tg), i.e., from 4.50 Tg in the early 1950s to 2.15 Tg in the late 2000s, due to a large wetland loss of 17.0 million ha. Of this reduction, 0.26 Tg (0.24–0.28 Tg) was derived from lakes and rivers, 0.16 Tg (0.13–0.20 Tg) from coastal wetlands, and 1.92 Tg (1.54–2.33 Tg) from inland wetlands.

Keywords: CH4 emissions, wetland, modelling, temporal variation, China


III
y=0.042x+7.5
R^2=0.17,p<0.001
I
y=0.067x+22.7
R^2=0.27, p<0.001
II
y=0.017x+5.7
R^2=0.24,p<0.001
V
y=0.054x+18.4
R^2=0.20,p<0.001
IV
y=0.050x+11.9
R^2=0.05,p=0.052
Wetland site
Coastal wetland
Inland wetland
Lake & river
CH_4 flux (g m^{-2} yr^{-1})
Year

Methane uptake in global forest and grassland soils over the period 1981-2010

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Methane (CH_4) is one of the most potent greenhouse gases. It is generally recognized that forest and grassland soils consume the atmospheric CH_4, but the quantities and spatiotemporal changes in the CH_4 uptake remain largely uncertain as far as global forest and grassland are concerned. Here, we estimated CH_4 uptake in global forest and grassland soils over the period of 1981-2010 using an empirical model developed in this study. We show that the mean values of CH_4 uptake were 9.16 (±3.83) Tg yr^{-1} in forest soils, and 3.76 (±1.42) Tg yr^{-1} in grassland soils, respectively. Tropical forest and grassland soils are the largest CH_4 sink, contributing 58% to the total sink. Methane uptake in cool temperate dry and warm temperate dry soils, and in polar/boreal grassland soils showed a significant increase, while a significant decrease was found in tropical dry grassland soils over the thirty years. Our findings highlight the quantities of CH_4 uptake in global forest and grassland soils, and underline the spatiotemporal changes in CH_4 uptake over the thirty years so as to better understand the impact of climate change on soil CH_4 sink.

Keywords: methane uptake, climate change

Implications of overestimated anthropogenic CO_2 emissions on East Asian CO_2 sources and sinks estimations

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Measurement and modelling of regional or country-level carbon dioxide (CO_2) fluxes are becoming critical for verification of the greenhouse gases emission control. One of the commonly adopted approaches is inverse modelling, where CO_2 fluxes (emission: positive flux, sink: negative flux) from the terrestrial ecosystems are estimated by combining atmospheric CO_2 measurements with atmospheric transport models. The inverse models assume anthropogenic emissions are known, and thus the uncertainties in the emissions introduce systematic bias in estimation of the terrestrial (residual) fluxes by inverse modelling. Here we show that the CO_2 sink increase, estimated by the inverse model, over East Asia (China, Japan, Korea and Mongolia), by about 0.26 PgC yr^{-1} (1 Pg = 10^{12} g) during 2001-2010, is suggested as an artifact of the anthropogenic CO_2 emissions increasing too quickly in China by 1.41 PgC yr^{-1}. Independent results from methane (CH_4) inversion suggested about 41% lower rate of East Asian CH_4 emission increase during 2002-2012. We apply a scaling factor of 0.59, based on CH_4 inversion, to the rate of anthropogenic CO_2 emission increase since the anthropogenic emissions of both CO_2 and CH_4 increase linearly in the emission inventory. We find no systematic increase in land CO_2 uptake over East Asia during 1993-2010 or 2000-2009 when scaled anthropogenic CO_2 emissions are used, and that there is a need of higher emission increase rate for 2010-2012 compared to those calculated by the inventory methods. High bias in anthropogenic CO_2 emissions leads to stronger land sinks in global land-ocean flux partitioning in our inverse model. The corrected anthropogenic CO_2 emissions also produce measurable reductions in the rate of global land CO_2 sink increase post-2002, leading to a better agreement with the terrestrial biospheric model simulations that include CO_2-fertlization and climate effects.

Keywords: East Asian Carbon Budget, Fossil Fuel Emission, Terrestrial Biospheric Uptake

Toward advanced inventory of regional and urban greenhouse gas emissions for carbon accounting

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Emissions of greenhouse gases distribute highly heterogeneously over land surface, including natural sources and sinks and anthropogenic sources. They have also different temporal variations, making it difficult to resolve observed atmospheric signals into specific sources. Advancing the mapping of land surface greenhouse gas sources and sinks is effective to improve credibility of not only bottom-up but also top-down estimates. In this study, we make an attempt to conduct regional-scale evaluation of greenhouse gases using several anthropogenic emission inventories and a process-based model of natural sources and sinks. We compare different inventory data to clarify the uncertainty in regional budget, putting the particular focus on Asian region and countries. The process-based model estimates greenhouse gas budget of forests, other natural lands, and croplands, taking account of atmospheric composition and deposition and fertilizer input. Having high spatial and temporal resolution would be a key feature of the new mapping, and so we try to use new land data for CMIP6. Finally, we discuss how the new emission mapping methodology and regional accounting are likely to make contributions to IPCC and UNFCCC.

Keywords: greenhouse gase emission inventory, carbon cycle, uncertainty

Development and validation of fine-scale gridded emission inventory of anthropogenic GHGs and air pollutants for Thailand

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Developing countries in Southeast Asia including Thailand are accomplishing rapid economic growth. This is resulting in significant increase of energy consumption, GHG emissions, and air pollution. Effective strategies are required to solve these energy related environmental issues, and hence to achieve sustainable development goals. Emission inventories of GHGs and air pollutants are essential to identify key sectors. In this regard, the main challenge is validating emissions estimated by bottom-up approaches-based inventories. Various top-down techniques based on satellite observations and inverse modeling have been developed to estimate emissions. Recent studies showed that it is quite effective to compare emissions derived from top-down and bottom-up approaches to get more accurate estimates.
The purpose of this study is to develop fine-scale gridded emission inventory of GHGs and air pollutants emitted from various anthropogenic sources in Thailand based on a bottom-up approach. GAINS-Asia model was utilized to estimate emissions of greenhouse gases including CO_2, CH_4, and N_2O, and precursors including CO, NH_3, NOx, SO_2, VOC, and PM (including BC, OC, $PM_{2.5}$, PM_{10}, and TSP) in Bangkok Metropolitan Region (BMR) and other four regions in Thailand in 2015. Activity data required to estimate emissions were collected from various national databases, and shares of control technologies were obtained from specific surveys and country-specific literature, whereas emission factors were the default values contained in GAINS-Asia model.
Total amounts of estimated CO_2, CH_4, N_2O, CO, NH_3, NOx, SO_2, VOC and $PM_{2.5}$ emissions for the whole Thailand in 2015 were 350, 3.7, 0.13, 1.8, 0.52, 0.83, 0.31, 0.65, and 0.34 Tg/year, respectively. Key emission sectors were power plants for CO_2, agriculture for CH_4, N_2O and NH_3, industrial processes for CO and VOC, road transport for NOx, and industrial combustion for SO_2 and $PM_{2.5}$. Differences of key sectors for each species imply difficulties to develop overall effective strategies.
The estimated emissions of the five regions were horizontally allocated into fine grids. Their resolution is 12 x 12 km for the whole Thailand and 1 x 1 km in BMR. Information of actual locations of power plants and industrial factories were used to allocate their emissions, whereas various surrogate information, e.g. population, traffic volumes, number of housings, etc., were utilized to allocate emissions of remaining sectors.
Air quality simulations using the regional meteorological model WRF and regional chemical transport model CAMx were conducted to validate the emission estimate in this study. The simulated concentrations of ambient air pollutants were compared to surface observations, and it was found that the observed seasonal variations were well reproduced by the simulations. However, absolute values of the observed concentrations were underestimated for CO, NO_2, and PM_{10}, and were overestimated for O_3. Further improvements of the emission inventory are therefore necessary. In addition, the simulated concentrations were significantly affected by biomass burning emissions, which extensively occurs in northern Thailand and Cambodia, especially during December to early April. Accurate estimates of their emissions are also critical to pinpoint dominant sources and to develop effective strategies.
The results from this study showed that air quality simulations could be one of effective ways to validate air pollutant emission inventory. Nevertheless, additional techniques should be explored, in order to completely validate the emission inventory including GHGs and improve the performance of air quality simulation.

Keywords: Emission inventory, GHG, air pollutant, Thailand

Satellite-based monitoring of extreme biomass burning across Southeast Asia in 2015 El Nino year.

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In 2015, an intense El Nino occurred and resulted in an extremely low rainfall in Indonesia and other countries in Southeast Asia during the dry season (e.g. Aug-Oct in Southern Borneo). In the same year, record breaking forest fires occurred in this region since the 2000, especially in southern Borneo and western Sumatera islands. The fire affected agribusiness, such as palm oil production and timber, and human health, such as respiratory tract infections. It also affected environmental conditions over greater region, by releasing large amount of CO2 and aerosol into the atmosphere. We analyzed multiple satellite-based datasets, e.g., OMI aerosol optical index, MODIS land surface temperature, active fire counts, and vegetation index, TRMM rainfall, and GFED (Global Fire Emissions Database) CO2 emission in order to quantify severity of biomass burning in 2015, relative to the period of 2005-2015. We identify major drivers of anomalous biomass burning in 2015 especially in the southern Borneo and western Sumatra islands. We found that anomalous weather (e.g. temperature and precipitation) developed since July led to fire occurrence in Southeast Asia during August to October as detected from MODIS active fire counts, aerosol optical index, and the amount of CO2 emission in the south of Borneo and Sumatra islands in 2015. Among climate variables, we detected a persistent low precipitation period before and during dry season in 2015 from SPI (Standardized Precipitation Index) data. The persistence of low precipitation period before and during dry season showed correlation with severity of biomass burning. Therefore, monitoring of persistence in anomaly of precipitation is one of the keys to predict the severity of biomass burning in Southeast Asia. Further analysis can be performed for CO2 emissions using near-realtime data from the GOSAT and OCO-2 satellites.

CO_2 flux variation in Southeast Asia for 2015 estimated by in-situ aircraft measurements

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The global carbon cycle changes in response to climate changes. However, our understanding of the mechanisms underlying those carbon cycle changes is still not enough and an earth system model with climate–carbon cycle feedback included has significant uncertainties in its global warming prediction. Observations of CO_2 mole fractions in the atmosphere has revealed significantly large impacts of El Nino-Southern Oscillation (ENSO) on the carbon cycle. Anomalous climate events associated with ENSO, such as high/low temperatures, dry/wet conditions and fires, may induce CO_2 flux changes at the earth surface and consequently CO_2 mole fraction changes in the atmosphere. In order to quantitatively estimate spatiotemporal variations of CO_2 fluxes from atmospheric observations, one uses an inversion analysis, which employs an atmospheric transport model to link surface fluxes with atmospheric mole fractions. However, the sparseness of the global CO_2 observation network has limited the reliability of the flux inversion analysis, specifically for tropical areas, where surface fluxes seem to have significant sensitivities to ENSO. In recent years, an in-situ aircraft measurement project named CONTRAIL (Machida et al., 2008) has extended the global CO_2 observation network; especially, the extension to Southeast Asia is noteworthy. In 2015, the year of the biggest El Nino since 1997, a number of fire events in Southeast Asia were clearly captured by satellites, suggesting that significant amount of CO_2 was released into the atmosphere. In this study, we have conducted an inversion analysis using an inversion system named NICAM-TM 4D-Var (Niwa et al., 2016a,b) and estimated CO_2 fluxes in Southeast Asia with a focus on changes related to the El Nino.

Keywords: Carbon Cycle, Data assimilation, aircraft, El Nino

The Orbiting Carbon Observatory (OCO-2) tracks 2-3 peta-gram increase in carbon release to the atmosphere during the 2014-2016 El Niño

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The powerful El Niño event of 2015-2016 –the third most intense since the 1950s –has exerted a large impact on the Earth’ s natural climate system. The column-averaged CO_2 dry-air mole fraction (XCO_2) observations from satellites and ground-based networks are analyzed together with in situ observations for the period of September 2014 to October 2016. From the differences between satellite (OCO-2) observations and simulations using an atmospheric chemistry-transport model, we estimate that, relative to the mean annual fluxes for 2013, over the period July 2015 to June 2016, the most recent El Niño has contributed to an excess CO_2 emission from the Earth’ s surface (land+ocean) to the atmosphere in the range of 2.4 ±0.2 PgC (1 Pg = 10^{15} g). The excess CO_2 flux resulted primarily from reduction in vegetation uptake due to drought, and to a lesser degree from increased biomass burning. It is about the half of the CO_2 flux anomaly (range: 4.4-6.7 PgC) estimated for the 1997/1998 El Niño. The annual total sink is estimated to be 3.9 ±0.2 PgC for the assumed fossil fuel emission of 10.1 PgC. The major uncertainty in attribution arise from error in anthropogenic emission trends, satellite data and atmospheric transport.

Keywords: OCO-2, GOSAT, ACTM, TCCON

Reduction in global area burned and wildfire emissions enhances carbon uptake by land

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The carbon uptake by land and ocean processes currently removes about 55% of the CO_2 emitted into the atmosphere by human activities. The carbon uptake over land is primarily the result of vegetation’s response to increasing atmospheric CO_2, but climate change, nitrogen deposition and other factors also play a role. Here, using results from a terrestrial ecosystem model we identify reduction in global wildfire CO_2 emissions as yet another mechanism that contributes to this carbon uptake over land. Our results show that since the 1950s increasing population densities and cropland area across the globe have acted to decrease area burned, consistent with the sediment charcoal record and the satellite-based observational record for the 1997-2014 period. The associated reduced wildfire emissions from cropland area increases do not enhance carbon uptake since vegetation that is spared wildfire burning was deforested anyway. However, the reduction in wildfire emissions due to population density increases, and the associated direct fire suppression and landscape fragmentation, is calculated to enhance carbon uptake by 0.16 Pg C yr^{-1}, or ~23% of the global rate of land carbon uptake (0.7±0.6 Pg C yr^{-1}), for the 1960-2009 period.

Keywords: Land carbon budget, Fire

FLUXCOM remote sensing data based CO_2 flux products: overview and synthesis

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Increases in availability of eddy-covariance observation network data and remote sensing data enable us to empirical estimation of CO_2 fluxes across global. In this study, we introduce FLUXCOM remote sensing data based products (FLUXCOM-RS). The product is established using FLUXNET observation data (~ 250 sites), remote sensing data (MODIS products), and multiple machine learning methods (e.g. Tramontana et al. 2016), and provides energy and carbon fluxes at 8-day temporal and 1/12 degree spatial resolutions from 2000 to 2015. The advantages of this products compared with the other FLUXCOM product (FLUXCOM based on gridded climate data; FLUXCOM-Met; Jung et al. 2017; Tramontana et al. 2016) are higher spatial resolution and purely satellite-based data driven estimation. Cross-consistency evaluation were conducted using available independent estimation of GPP and NEE. Sun-Induced Fluorescence from GOME-2 and GOSAT data were used to test consistency of FLUXCOM-RS GPP seasonal and interannual variations. Atmospheric inversion outputs based on in-site atmospheric CO_2 measurement and GOSAT based CO2 concentration were used to evaluate FLUXCOM-RS NEE. Furthermore, existing upscaled GPP and NEE at global scale (Jung et al. 2011; Kondo et al. 2015; Jung et al. 2017) and regional scale (Ueyama et al. 2013; Ichii et al. submitted) were also compared. FLUXCOM-RS GPP and NEE are generally consistent with other estimations, such as SIFs and inversion-based net CO_2 fluxes over temperate and boreal region in terms of mean seasonal variation. In addition, interannual variations in FLUXCOM-RS GPP are consistent with those of SIFs at sub-continental scales over temperate and boreal regions. On the other hand, discrepancies in GPP and NEE were found over tropical regions, e.g. Amazon. The FLUXCOM-RS products also show generally consistent seasonal variation with regional specific empirical upscaling in Alaska and Asia. Therefore, these products could also be used for regional analysis. The comparison with FLUXCOM-Met shows that FLUXCOM-RS products capture more clear spatial patterns in CO_2 fluxes, and only FLUXCOM-RS can capture CO_2 flux changes due to human activity (e.g. afforestation, fire). These evaluation suggests that FLUXCOM-RS be a promising and provide additional data sets to analyze terrestrial carbon and energy cycles.

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Keywords: Terrestrial Carbon Cycle, Data-driven model, FLUXNET, FLUXCOM, Remote Sensing

Carbon sequestration under no-tillage agriculture limited by climate conditions

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Years ago, no-tillage agriculture was believed to sequester atmospheric carbon oxide (CO_2) in soil for mitigating global warming. Recent years, evidence is mounting that potential of sequestering C in no-till farming are highly overstated, and scientists caution that the role of no-till practice in climate change mitigation is challenging. But the heterogeneous effect of no-till to soil carbon accumulation of croplands over the world was not clarified. We propose that gain or loss of soil carbon under no-till subjected to climate conditions. Minor gain of soil carbon was occurred in regions with T/P ratio (annual air temperature, ºC/ precipitation, m) large than 12, while regions with T/P ratio less than 12 had potential risk of carbon loss. We recommend that for regions with high temperature or low precipitation, no-tillage agricultural should contribute to carbon sequestration and benefit soil erosion. While, we take the precaution of regions with low temperature as well as heavy precipitation should pay close attention to management practices of farmers.

Keywords: Soil carbon, No-tillage, Temperature/precipitation ratio