Abstract Collection

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SCIAMACHY and GOSAT XCO_2 and XCH_4 retrievals:

The GHG-CCI CRDP3 data set

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The GHG-CCI project (http://www.esa-ghg-cci.org/) is one of several projects of the European Space Agency's (ESA) Climate Change Initiative (CCI). The goal of the CCI is to generate and deliver data sets of various satellite-derived Essential Climate Variables (ECVs) in line with GCOS (Global Climate Observing System) requirements. The "ECV Greenhouse Gases" (ECV GHG) is the global distribution of important climate relevant gases – specifically atmospheric CO_2 and CH_4 - with a quality sufficient to obtain information on regional CO_2 and CH_4 sources and sinks. The main goal of GHG-CCI is to generate long-term highly accurate and precise time series of global near-surface sensitive satellite observations of CO_2 and CH_4. SCIAMACHY on ENVISAT and TANSO-FTS/GOSAT are the two main satellite instruments used within the GHG-CCI project as their spectral radiance observations in the near-infrared range of the electromagnetic spectrum permit retrievals of CO_2 and CH_4 columns that are sensitive down to the Earth's surface and because multi-year time series can be derived from these data. In addition other satellite instruments such as IASI/METOP and MIPAS/ENVISAT are also used. In the presentation an overview about the latest data set – the so-called Climate Research Data Package 3 (CRDP3) - will be given focusing on SCIAMACHY and GOSAT XCO_2 and XCH_4. Furthermore, selected highlights from using the GHG-CCI data products to address important questions related to the sources and sinks of CO_2 and CH_4 will be presented.

Keywords: SCIAMACHY, GOSAT, carbon dioxide, methane, retrieval, validation

Summary of NIES GOSAT Project: Activities Over the Past Seven Years and Plans for the Next Five Years

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The Greenhouse gases Observing SATellite (GOSAT) has been operating for more than seven years ever since its launch in January 2009. We will continue with distribution of our GOSAT standard data products through the GOSAT User Interface Gateway (GUIG). Over the past seven years, the GOSAT data products and the data distribution methods were updated several times. In this presentation, we will first explain the history of GOSAT data product distribution and then a tentative plan for the near-real-time and full-term data processing and the delivery of GOSAT data products and related information via GUIG and GOSAT project websites over the next five years.

Also, we will touch on the current status of researches conducted within the framework of the GOSAT Research Announcement. Reports on GOSAT-related studies, both ongoing and already completed, have appeared in scientific journals more than a hundred times. We expect that continuing synergistic collaboration among the researchers of GOSAT, OCO-2, and future space-based GHG monitoring missions will lead to even more new findings and advances in carbon cycle studies.

Keywords: GOSAT, project, overview, product, research

The Orbiting Carbon Observatory-2 (OCO-2) Version 7 Data Product

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The NASA Orbiting Carbon Observatory-2 (OCO-2) was successfully launched on 2 July 2014. Two months later, its 3-channel imaging grating spectrometer began routinely returning almost one million soundings each day over the sunlit hemisphere. Typically, 5 to 13% of these soundings are sufficiently cloud free to yield full-column estimates of the column-averaged CO_2 dry air mole fraction, X_{CO2}.
The OCO-2 team began delivering Version 7 data product to the Goddard Earth Sciences Data and Information Services Center (GES-DISC) in early June 2015. These products include calibrated, spectral radiances (Level 1b products) and retrieved geophysical quantities, including spatially-resolved estimates of X_{CO2}, surface pressure, water vapor, aerosols, and solar-induced chlorophyll fluorescence (Level 2 products). The calibration of the Level 1 products is being validated and refined using measurements of onboard lamps, diffuse sunlight, the lunar disk, and ground-based vicarious calibration sites, such as Railroad Valley Nevada, which is also routinely observed by the Japanese Greenhouse gases Observing SATellite, GOSAT. The Level 2 products are being validated against observations from the Total Carbon Column Observing Network (TCCON) and other standards to identify and correct biases. These comparisons indicate that OCO-2 returns X_{CO2} estimates with single-sounding random errors between 0.5 and 1 ppm at solar zenith angles as large as 70 degrees. Biases between OCO-2 and TCCON X_{CO2} estimates are typically < 2 ppm, and a simple bias correction algorithm can reduce these differences to near 1 ppm at most sites. However, more anomalous values are seen in some regions. For example, glint observations over mid-to-high-latitude ocean (30-50 S) appear to be biased 2-5 ppm high relative to TCCON and other standards during the Southern hemisphere winter (June – August). Meanwhile, X_{CO2} over the tropical ocean appears to be biased ~0.5 ppm low relative to models. These and other possible errors are currently under investigation.

Keywords: OCO-2, Carbon dioxide, CO_2, retrieval algorithms, calibration

Building capacity to access and use greenhouse gas observations

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Paris Agreement was adopted in United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties (COP) 21 in December 2015. Furthermore, Sustainable Development Goals (SDGs) have been set by the UN General Assembly in New York in September 2015. Next step is implementation of Paris Agreement and SDGs and support is necessary for developing countries to implement them.

Space-based observation data, coupled with ground-based observation, is useful to get a good grasp of inventory of greenhouse gas (GHG) emissions in developing countries and to crosscheck the accuracy of built-up inventory. In developing countries, due to the lack of robust in-situ data, space-based data plays a key role in understanding climate change and promoting mitigation. However, access to, and use of, space-based data in many developing countries is very weak, largely due to lack of institutional and human capacity.

Building on its experience in Earth observation related capacity building, START would like to propose a capacity development program focused on access to, and use of, GHG observation in collaboration with the National Aeronautics and Space Administration (NASA), the Ministry of the Environment Japan (MOEJ), the Japanese Aerospace Exploration Agency (JAXA) and the National Institute for Environmental Studies (NIES). The principal objective of the proposed program is to promote climate change mitigation in developing countries (especially at the regional and urban scales in the Asia-Pacific region) through innovative and practical uses of greenhouse gas satellite data. It is instructive to note that NASA, MOE, JAXA and NIES have signed a Memorandum of Understanding regarding cooperation on the OCO-2 and GOSAT/-2 , missions in March 2015. The proposed program would start by a pilot phase in which a set of training activities (with OCO-2 and GOSAT/-2 data on GHG fluxes from 2-3 Asian mega-cities, which would help in the collection of additional base-line data as to capacity and knowledge needs associated with the content of the training.

Keywords: GOSAT, OCO-2, GOSAT-2, START, capacity building

How GOSAT has provided uniform-quality spectra and optimized global sampling patterns for seven years

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Since April 2009, the Greenhouse gases Observing SATellite (GOSAT) has been providing long-term Level 1B radiance spectra with uniform quality even after suffering three major satellite system anomalies: a failure of one of the two solar paddles in May 2014, a switch to the secondary pointing system in January 2015, and a cryo-cooler shutdown and restart in August 2015. A unique agile pointing mechanism has optimized the global sampling patterns. In August 2015, the Level 1 algorithm V201.201, which is the first major version since the launch of the satellite, was released and both V161.160 and V201.201 have been processed in parallel. Using the V201.201 algorithm by JAXA super computer system (JSS2), the dataset collected over more than six years with the same spectral resolution after the correction of the large ZPD shift was reprocessed with about 10 times faster than the using the former versions in the original system.

GOSAT had started performing global observations with simple grid observations. Greenhouse gas emissions with fine spatial scales should now be captured considering spatial correlations and sampling patterns have been modified. The settling of the secondary pointing system is more stable than the primary, which was used until December 2014, and the pointing offset is well characterized and easily corrected. There is no need to reduce the range of the secondary system along track (AT) any more. The daily planned target observations will enable (1) maximizing the target observations of large emission sources (2) deriving point source emission directly by measuring both up-and-down wind references and emission points (3) extension of sun glint observation to higher latitude by not only tracking the specular reflection point but also brighter area in the principal plane including the sun, GOSAT and ocean surface, (4) tuning the viewing geometry to minimize the geometry dependent errors.

Keywords: GOSAT, Level 1B, target observations

Updates to Spectroscopy for the OCO-2 mission

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The Orbiting Carbon Observatory (OCO-2) mission measures spectrally resolved radiances in the 1.61 μm and 2.06 μm CO_2 bands and the 0.76 μm O_2 A-band. These measurements are analyzed with remote sensing retrieval algorithms to yield estimates of the column-averaged CO_2 dry air mole fraction, X_{CO2}. The goal is to obtain X_{CO2} with uncertainty of 0.25% (1 ppm out of the 400 ppm background), in order to provide the information needed to understand carbon sources and sinks on regional scales over the globe. This goal places stringent demands on the accuracy of the spectroscopic input to the OCO-2 forward model. To address these demands, efforts are underway to incorporate advanced line-shape formulations and to derive improved experimental line parameters. Advances in spectroscopy are included in the OCO-2 forward model by way of updates in the look-up tables for molecular absorption coefficients (ABSCO tables).

Here we present recent updates to OCO-2 ABSCO tables. These updates include results from a new multispectrum analysis of O_2 A-band spectra acquired over a wide range of temperature and pressure, where details of the line-shape, the extent of line-mixing and the collision-induced absorption were determined in a self-consistent model. The updates also include results of new multispectrum analyses of the 1.61 μm and 2.06 μm CO_2 bands with improved constraints on the temperature dependence of the spectroscopic parameters for these bands. We present results of validation of these spectroscopic updates using ground-based atmospheric spectra and retrievals from the Total Carbon Column Observing Network (TCCON) site in Lamont, Oklahoma as well as satellite-based spectra and retrievals from OCO-2. In addition to showing the reduction in residuals and retrieval biases associated with the updates, we will discuss outstanding issues and potential paths to resolving these.

Keywords: OCO-2, oxygen, carbon dioxide, spectroscopy, retrieval

A New BRDF Model to Reduce Biases in Orbiting Carbon Observatory-2 (OCO-2) Retrievals

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The Orbiting Carbon Observatory-2 (OCO-2) is NASA's first dedicated Earth remote sensing satellite to study atmospheric carbon dioxide from space, and was launched successfully on July 2, 2014. Retrievals in the target mode (where the Observatory locks its view onto a specific surface location, and scans back and forth over that target while flying overhead) show biases that appear to be due to not accounting for bidirectional surface reflection (BRDF) effects, i.e., the non-isotropic nature of surface reflection. To address this issue, we implement a realistic BRDF model. The column averaged CO_2 dry air mole fraction (XCO_2) results using this new model show much less variation with scattering angle (or airmass). Further, the retrieved aerosol optical depth (AOD) is in much better agreement with coincident AERONET values. We also show results using the BRDF model on land nadir and glint measurements, and measurements over Total Carbon Column Observing Network (TCCON) sites.

Keywords: OCO-2, BRDF, retrieval

Reprocessed Warn Levels and their Influence on Bias Correction for OCO-2 v7

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Warn Levels (WL) have proven to be of use for the quick creation of specific, custom filtration of OCO-2 data for a particular user's analysis and data quality estimation. For v7, the original WL's were generated using data that spanned only the then-available seven months (2014-09 to 2015-04). We have now regenerated the formula for WL and Bias Correction using more than 17 months of data, creating more robust, generalizable products to present and future soundings. The stability of the Bias Correction as a function of WL filtration will also be addressed.

Keywords: OCO-2 v7 Warn Levels WL Data Filtration

FTS methane profile retrieval using dimension reduction method

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The ground based Fourier Transform Spectrometer (FTS) instrument at Sodankylä (67.368N, 26.633E), Northern Finland is part of the Total Carbon Column Observing Network (TCCON), which is a global network that observes solar spectra in near-infrared wavelengths to measure greenhouse gases, carbon dioxide and methane.

The high spectral resolution of the FTS data provides approximately three degrees of freedom about the vertical structure of methane between around 0 and 40 km. Here we utilize this information to retrieve some vertical information of the methane profile.

We introduce an inversion method that uses dimension reduction for the retrieval of atmospheric methane profiles. Uncertainty analysis is performed using the Markov chain Monte Carlo (MCMC) statistical estimation. In the retrieval, we use Bayesian framework with adaptive MCMC to better characterize the full posterior distribution of the solution and uncertainties related to the retrieval. The retrieved profiles are visually in good agreement with in-situ AirCore soundings, which provide an accurate reference up to 20–30 km.

This work is linked to GOSAT RA on “Validation of the retrieval algorithms of GOSAT-FTS and Sodankylä FTS instruments”

Keywords: FTS, TCCON, methane, retrieval, vertical profile, MCMC, adaptive MCMC, posterior distribution, dimension reduction

EOF-based regression algorithm for the fast retrievals of XCO_2 from the GOSAT observations

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PPDF-based algorithms were developed in NIES to provide fast and accurate retrievals of XCO_2 and XCH_4 from GOSAT SWIR-FTS. We propose further development of PPDF-S algorithm to improve the retrieval accuracy under the conditions of high aerosol loading and to increase the number of successfully processed GOSAT scans. The algorithm modifications include, among others, new a priori constraints on target gas amounts and optical path that are derived by EOF (Empirical Orthogonal Functions)-based regression technique.

The presentation focuses on the implementation of this technique for the fast retrieval of XCO_2 that involves 1) extraction of compact information from measured spectral radiance by its EOF decomposition; followed by 2) derivation of regression formulae that relate the extracted information with gas amounts using training sets of collocated GOSAT and ground-based observations. The retrieval accuracy was shown to depend critically on the selection of the training set that should cover the variability of XCO_2 and observation conditions (e. g. airmass, surface pressure, etc.).

Keywords: GOSAT, carbon dioxide, retrieval, algorithm

Application of TanSat retrieval algorithm on GOSAT Observation (ATANGO): global retrieval and product application

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China’s carbon dioxide observation satellite (TanSat) will be launched in 2016. A hyperspectral grating spectrometer onboard the TanSat will monitor the column-averaged CO_2 dry-air mixing ratio (XCO_2) in global. Application of TanSat retrieval algorithm on GOSAT Observation (ATANGO) has been developed to approach XCO_2 in using GOSAT data. In order to apply the algorithm on global data retrieval, we developed a fast radiative transfer model that shows a highly precision on Stokes parameters simulation and well performance on calculation efficiency. Global retrieval experiment has been carried out with GOSAT L1B 161160 data of 2012, and validated using The Total Column Carbon Observing Network (TCCON) measurements. The retrieved XCO_2 agree well with TCCON measurements in a low bias of 0.15 ppm and RMSE of 1.48 ppm, and captured the seasonal variation and increasing of XCO_2 in Northern and Southern Hemisphere respectively as other measurements. A post-screening filter was used to control data quality, and a multiple regression of polynomial coefficient was applied on global XCO_2 bias correction. ATANGO V1.4 product was now used in carbon flux inversion preliminary.

Keywords: GOSAT, retrieval, carbon dioxide, remote sensing

Improvement of CO_2 retrieval algorithm with modified aerosol information using GOSAT measurements over East-Asia

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The Yonsei CArbon Retrieval (YCAR) algorithm, developed by Yonsei University, retrieves the column-averaged dry-air mole fraction of carbon dioxide (XCO_2), which is based on optimal estimation method using shortwave infrared (SWIR) channels. In sensitivity analysis using simulated radiance spectra at difference surface and atmospheric conditions, the aerosol-related parameters representing the vertical distribution and optical properties of aerosols are important factor in XCO_2 retrievals, resulting in errors up to 2.5 ppm due to inaccurate aerosol optical information.

As aerosols in the atmosphere are highly variable in their amount, vertical distribution and optical properties, their effect can be under-constrained (Frankenberg et al., 2012). These errors are caused by the simplified or inaccurate aerosol assumptions in the forward model and can be also increased in CO_2 retrieval using real-spectra. To reduce the errors caused by the simplified aerosol assumptions, the YCAR algorithm are modified by using 12 parameters, representing aerosol vertical distribution and its optical properties instead of AOD profiles used in previous version. The XCO_2 retrievals with two different approaches in handling aerosol information analyzed using the Greenhouse Gases Observing SATellite (GOSAT) spectra over East-Asia and evaluated through the comparison with collocated ground-based observations at several Total Carbon Column Observing Network (TCCON) sites. These results can improve the accuracy of CO_2 retrieval algorithm taking into account aerosol information and provide useful information to reduce uncertainty and increase data availability.

Keywords: GOSAT, carbon dioxide, methane, retrieval, validation

Lower-tropospheric CO_2 from near infrared ACOS-GOSAT observations

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We demonstrate a new measurement from the near infrared GOSAT observations, the lowermost tropospheric column (LMT-CO2). The ACOS-GOSAT intermediate retrieved CO_2 profile is divided into two quantities: the LMT-CO2 partial column from 0-2.5 km, and the U-CO_2 partial column from 2.5 km to the top of the atmosphere. Each partial column contains, on average, 0.8 degrees of freedom. We characterize LMT-CO_2 observations through comparisons to aircraft profiles and remote surface observations, demonstrating that the LMT-CO_2 improves over the initial guess/prior and demonstrates a seasonal cycle unique from XCO_2. We look at two interesting regions using these new products: biomass burning source versus outflow in the southern Hemisphere, and the longitudinal variations of the seasonal cycle in the 45-53N range.

Keywords: GOSAT, surface CO_2

Amazon Column CO_2 and CO Observations from Ground and Space to Evaluate Tropical Ecosystem Models

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The Amazon basin stores 150-200 PgC, exchanges 18 PgC with the atmosphere every year and has taken up 0.42-0.65 PgC/y over the past two decades. Despite its global significance, the response of the tropical carbon cycle to climate variability and change is ill constrained. The complex interplay of radiation, water and ecosystem phenology remains unresolved in tropical ecosystem models. We use high frequency regional scale TCCON observations of column CO_2, CO and CH_4 near Manaus, Brazil that began in October 2014 to understand the aforementioned interplay of processes. We observe a robust daily column CO_2 uptake of about 2 ppm (4 ppm to 0.5 ppm) over 8 hours and evaluate how it changes as we transition to the dry season. Back-trajectory calculations show that the daily CO_2 uptake footprint is terrestrial and influenced by the heterogeneity of the Amazon rain forests. The column CO falls from above 120 ppb to below 80 ppb as we transition from the biomass burning to wet seasons. The daily mean column CO_2 rises by 3 ppm from October through June. Removal of biomass burning and secular CO_2 increase during this period implies an increase of 3.5 ppm that is attributed to tropical biospheric processes (respiration and photosynthesis). This is consistent with ground-based and eddy flux observations that indicate that tree phenology (e.g. leaf flushing) plays an important role in the tropical carbon cycle in regions that are not water limited and is not considered in current models. We compare our observations with output from carbon cycle models with assimilated meteorology and find they under predict the daily drawdown of CO_2 by a factor of 3. We report comparisons with other models and also determine the net carbon flux from the Amazon basin by combining back-trajectory analysis and observations of column CO_2. Finally, we evaluate and use OCO-2 CO_2 and Solar Induced Fluorescence observations over the Amazon to elucidate the tropical carbon cycle.

Keywords: TCCON, OCO-2, GOSAT, carbon dioxide, carbon climate feedback, Amazon, rainforest, validation

East Asia Regional CO_2 Concentrations Observed by GOSAT – Spatial and Seasonal Variations

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This study aims to investigate the spatial and seasonal patterns of CO_2 concentration over the East Asia region using the GOSAT data acquired from June 2009 to February 2014. We firstly calculated mean CO_2 concentrations at 1°x1° nodes and then conducted semivariogram analysis on CO_2 concertrations. An example of the 1°x1° mean CO_2 concentrations is shown in Figure 1. Seasonal semivariograms (Spring – March, April, and May; Summer - June, July, and August; Autumn - September, October, and November; Winter – December, January, and February) were established from the 1°x1° mean CO_2 concentrations. CO_2 concentrations (at 1°x1° resolution) of different countries and seasons were then estimated by spatial interpolation of ordinary kriging. As an example, seasonal CO_2 concentrations in 2010 in China are demonstrated in Figure 2. More detailed results in other regions will be presented at the conference.

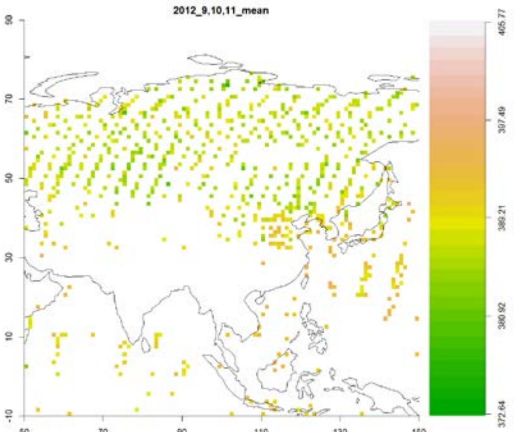

Figure 1. 1°x1° mean CO_2 concentrations of the Autumn season in 2012.

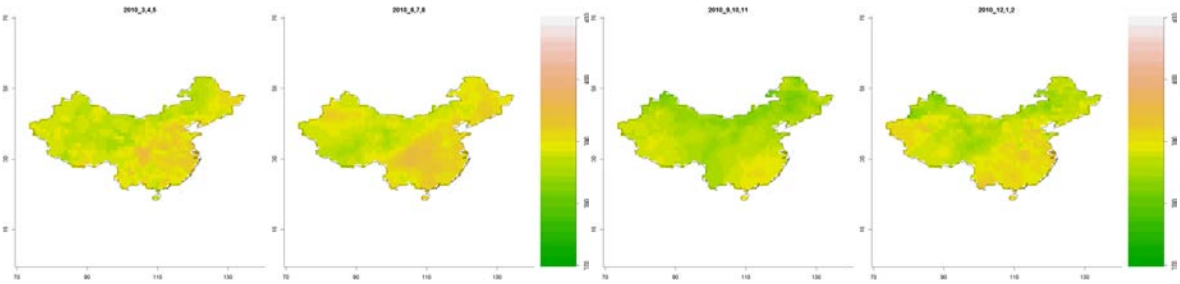

Figure 2. Seasonal variation of 1°x1° mean CO_2 concentrations in China in 2010.

Keywords: GOSAT, semivariogram, kriging, spatiotemporal variation

An intercomparison of retrieved X_{CO2} based on the H and M gain GOSAT and OCO-2 spectra over the central Australia

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The Greenhouse gases Observing SATellite (GOSAT) has been monitoring the global CO_2 and CH_4 distribution since April 2009. The retrieved X_{CO2} and X_{CH4} based on GOSAT are actually supporting the elucidation of carbon cycle. The satellite based monitoring system is a powerful tool for directly deriving the contrast of CO_2 and CH_4 emission and absorption related with geo-location such as city, forest, and wetland. However, it is required the consistent data quality under the different observation condition. In the previous version of GOSAT products, they have different biases against H and M gain spectra of GOSAT. Improvement of both level 1 and level 2 algorithms makes the difference in retrieved X_{CO2} small. To identify the remaining difference on X_{CO2}, an intercomparision of retrieved X_{CO2} based on H and M gain GOSAT spectra with NIES, ACOS and RemoTeC algorithms is carried out. Since February 2012, the periodical observation with H and M gain are started over the central Australia. Generally, the gradients of CO_2 against latitude and longitude over southern hemisphere are similar. To classify the difference between H and M gain based X_{CO2}, these products are reanalyzed with X_{CO2} derived from OCO-2 spectra. In parallel, the X_{CO2} based on the new L1B produce of v201 is also compared. The character of H and M gain based X_{CO2} will be presented from instrument point of view.

Keywords: GOSAT, X_{CO2}, Level 1B, ACOS, RemoTeC

Update on Validation of OCO-2 Observations of Column-Averaged Mole Fractions of Carbon Dioxide (XCO2)

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NASA's Orbiting Carbon Observatory (OCO-2) satellite was successfully launched on July 2, 2014 into low-Earth orbit, and measures near infrared spectra of sunlight reflected off the Earth's surface. The OCO-2 data record begins in September 2014 and the instrument continues to provide global observations of column-averaged dry-air mole fractions of carbon dioxide (XCO2).

OCO-2 has three observation modes, nadir, glint and target. Target mode observations were specifically designed for validation of the OCO-2 data. The target mode data from OCO-2 provide a large number of observations over a small geographic area. This allows for the assumption that the XCO2 over the observed area should be constant. The validation of OCO-2 data involves comparison to measurements from the Total Carbon Column Observing Network (TCCON). TCCON instruments measure XCO2 at similar wavelengths to OCO-2 and provide a "ground truth" for validation analysis.

The presentation will provide the latest results from comparisons of OCO-2 data to TCCON for all viewing modes. It will provide details on how surface properties (altitude, surface brightness) affect the OCO-2 measurements. We will also show results from validation/evaluation analyses from aircraft data and other sources.

Keywords: OCO-2, carbon dioxide, XCO2, TCCON, validation, measurement bias

Processes inferred from CH_4 and CO_2 observed during the airborne GLAM campaign above the Mediterranean Basin

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The Gradient in Longitude of Atmospheric constituents above the Mediterranean basin (GLAM) airborne campaign has been set up to investigate the variability of gaseous pollutants, greenhouse gases and aerosols between the West (~3°E) and the East (~35°E) of the Mediterranean Basin in summer. This campaign was organized in the framework of the Chemistry-Aerosol Mediterranean Experiment (CHARMEX) programme. During the campaign, several instruments including the Spectromètre InfraRouge In situ Toute altitude (SPIRIT) instrument aboard the Falcon-20 aircraft from the Service des Avions Français Instrumentés pour la Recherche en Environnement (SAFIRE; http://www.safire.fr) and base instruments from this aircraft measured aerosols, winds, radiation, humidity and chemical compounds such as O_3, CO, CH_4, N_2O, and CO_2. The campaign took place from 6 to 10 August 2014 from Toulouse (France) to Larnaca (Cyprus) and back, via Minorca Isl. (Spain), Lampedusa Isl. (Italy) and Heraklion (Crete Isl., Greece). The aircraft flew at an altitude of about 5.4 km above mean sea level (amsl) to go and at about 9.7 km amsl to return. Vertical profiles of different species and aerosols from the surface to about 12 km amsl in the vicinity of the landing sites listed above have been measured during the campaign. This paper presents an overview of the CH_4 and CO_2 measurements and of the scientific results obtained during GLAM combining surface station measurements, modeling and chemical forecasts and analyses.

Different processes were analyzed along an East-West axis or along the vertical, as follows. 1) Intercontinental transport and origin attribution: we demonstrate that the biomass burning with CH_4-enriched air from northern America, and CH_4-depleted and CO_2-enriched maritime boundary layer air masses from the Arabian Sea impacted the upper tropospheric Mediterranean Basin after 10-15 days of transport. 2) Air mass subsidence: the vertical stratification of the atmosphere from Lampedusa to Larnaca as deduced from CH_4 and CO_2 profiles helped the quantification of the vertical descent of air masses over the central-eastern Mediterranean Basin. It is estimated to be about 2.5 and 1.4 cm s^{-1} at 10 and 5.5 km altitude, respectively, consistently with meteorological analyses. 3) East-West greenhouse gases variability: comparisons between GLAM in situ measurements and assimilated spaceborne GOSAT CO_2 and CH_4 and IASI CH_4 measurements at 5-km altitude were consistent within ±15 ppbv for CH_4 and ±3 ppmv for CO_2 despite a systematic difference in CO_2 of about +5 ppmv (within the SPIRIT accuracy of 8 ppmv). 4) Coincident measurements from surface stations: GLAM CH_4 shows a systematic negative difference against surface CH_4 of –20 (±10) ppbv (within the SPIRIT accuracy of 20 ppbv) whilst CH_4 modeling analyses show a systematic positive difference of +17 (±3) ppbv. GLAM CO_2 shows a systematic positive but not significant difference against surface CO_2 of +6 (±1) ppmv whilst modeling analyses tend to show a negative difference against surface data of –6 (±1) ppmv.

Keywords: CH_4, CO_2, airborne, surface, modeling, long-range transport, subsidence

Surface Modelling of CO_2 Concentrations based on Flight Test of TanSat Instruments

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The Carbon Dioxide Observing Satellite (TanSat) is to be launched in early September 2016, to monitor global atmospheric concentration and flux of CO_2 from space. A flight test was conducted over a 120km×320km region in JiLin province of China to check stability and operationally efficient of TanSat instruments. The Bremen optimal Estimation DOAS (BESD) algorithm, a combination of optimal estimation with the weighting function modified differential optical absorption spectroscopy approach (WFM-DOAS), was used to retrieve CO_2 from the short-wavelength infrared spectra obtained using the flight test instruments. A method for high accuracy surface modelling (HASM) was employed to interpolate the retrieved CO_2 into surfaces in the flight test region.

In the meanwhile, a ground observation network (GON) was established for validating the results from the flight test. In the test region, land cover types include forest, water area, farmland, grassland, wetland, industrial area and urban area. The GON consisted of 11 carbon dioxide detectors that combined with automatic weather stations together. It was operated during the period from 19 August to 18 September of 2015. The correlation between carbon dioxide concentration and environmental variables were statistically analyzed by using data from the ground observation network in the TanSat flight test area. The spatial distribution of carbon dioxide concentration in surface layer was simulated by means of HASM combining with the results of statistical analysis.

The surfaces, respectively from retrieved CO_2 concentrations and from the ground observation network, were comparatively analyzed.

Keywords: TanSat, carbon dioxide, flight test, retrieval, ground observation network, validation

Distinguishing small scale CO_2 emission structures using OCO-2

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Localized CO_2 emission structures cover spatial domains of less than 50 km diameter and include cities and transportation networks, as well as fossil fuel production, upgrading and distribution infra-structure. Anthropogenic sources increasingly upset the natural balance between natural carbon sources and sinks. Mitigation of resulting climate change impacts requires management of emissions, and emissions management requires monitoring, reporting and verification. Space-borne measurements provide a unique opportunity to detect, quantify, and analyze small scale and point source emissions on a global scale.

The July 2014 launched Orbiting Carbon Observatory (OCO-2), now leads the afternoon constellation of satellites (A-Train)Its continuous swath of 2 to 10 km in width and eight footprints across can slice through coincident emission plumes and may provide momentary cross sections. OCO-2 results demonstrate that we can detect localized source signals in the form of urban total column averaged CO_2 enhancements of 2-6 ppm against suburban and rural backgrounds. We will show results from Los Angeles, Tokyo, and Detroit, where OCO-2's multi-sounding swath observing geometry reveals intra-urban spatial structures reflected in X_{CO2} data, previously unobserved from space. The transition from single-shot GOSAT soundings detecting urban/rural differences (Kort et al., 2012) to hundreds of soundings per OCO-2 swath opens up the path to future capabilities enabling urban tomography of greenhouse gases.

For singular point sources like coal fired power plants and volcanoes, we have developed proxy detections of plumes using bands of imaging spectrometers with sensitivity to SO_2 in the thermal infrared (ASTER). This approach provides a means to automate plume detection with subsequent matching and mining of OCO-2 data for enhanced detection efficiency and validation.

Keywords: OCO-2, carbon dioxide, point sources, volcanoes, cities

A Preliminary Result on Characteristics of Temporal Column Abundances of CO_2 and CH_4 from the Ground-based FTS at Anmyeondo, Korea during 2014-205

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Anmyeondo Fourier Transform Spectrometer (FTS) site, located at the mid-west part of the Korean peninsula, has operated since March 2013. Used FTS is a Bruker IFS-125HR model which has a significantly high spectral resolution by 0.02 cm^{-1}. Specific instrumentation of Anmyeondo FTS site is almost similar to the requirement of Total Carbon Column Observing Network (TCCON). It is found that measured spectra have a good agreement with simulated spectra and monthly modulation efficiency (ME), which indicates the spectral accuracy of FTS measurement, has been recorded the vicinity of 99.9% since Feb 2015. The ME of 98% is regarded as the error of 0.1% in the ground-based in-situ CO_2 measurement.

Total column abundances of CO_2 and CH_4 during 2015 are estimated by using GGG v14 and compared with ground-based in-situ CO_2 and CH_4 measurements at the height of 86 m above sea level. The seasonality of CO_2 is well captured by both FTS and in-situ measurements while there is considerable difference on the amplitude of CO_2 seasonal variation due to the insensitivity of column CO_2 to the surface carbon cycle dynamics in nature as well as anthropogenic sources. Total column CO_2 and CH_4 approximately vary from 395 ppm to 405 ppm and from 1.82 ppm to 1.88 ppm, respectively. It should be noted that few measurements obtained in July to August because of a lot of cloud and fog. Enhancement of CH_4 from the FTS at Anmyeondo during summer and autumn well corresponds to that from ground-based in-situ CH_4 observation.

Keywords: FTS, CO_2, CH_4, TCCON

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 fractions of atmospheric CO_2 and CH_4 (XCO_2 and XCH_4, respectively) retrieved from Greenhouse gases Observing Satellite (GOSAT) measurements through the photon path length probability density function (PPDF) based retrieval method that simultaneously derives target gas abundance and PPDF parameters (PPDF-S). 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 ± 2.09 ppm for XCO_2 and 0.66 ± 15.41 ppb for XCH_4), on the other hand, FP retrievals have negative biases (-0.29 ± 2.33 ppm for XCO_2 and -2.23 ± 13.14 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 aerosols.

Keywords: GOSAT, carbon dioxide, methane, validation

Continuous in-situ measurements of CO and CO_2 concentrations and CO_2 isotope ratios (^{13}C, ^{18}O) in Nagoya city: Towards CO and CO_2 simultaneous measurements by GOSAT-2 satellite

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The GOSAT-2 satellite is planned to observe CO and CO_2 column concentrations simultaneously from the space. Atmospheric CO_2 concentrations in urban areas are influenced by the emission or absorption based on the biogenic respiration and photosynthesis, as well as the emission from fossil fuel combustion. The simultaneous measurements of CO and CO_2 column concentrations enable to identify the contributions of the anthropogenic and biogenic processes. We report the analyses of the ground-based in-situ measurements of CO and CO_2 concentrations and CO_2 isotope ratios ($\delta^{13}C$, $\delta^{18}O$) in the summer and winter in the urban area of Nagoya city. The isotope ratios of CO_2 provide more information about the sources of atmospheric CO_2 emissions. We discuss what can be derived from the simultaneous observation of CO and CO_2, and how in-situ observations can support the analyses of the satellite data.

The simultaneous measurements of CO and CO_2 concentrations and CO_2 isotope ratios were conducted in the summer (July 22-Aug. 11, 2012) and winter (Nov. 22-Dec. 11, 2011) at Nagoya University. The CO concentration was obtained by the NDIR CO analyzer (Thermo). The CO_2 isotope ratios were measured by the mid-IR (4.3 μm) laser absorption spectrometer (Aerodyne) with a high precision (> 0.2‰). The gas handling system keeping CO_2 concentration constant at 350 ppm was developed and installed to improve the accuracy of CO_2 isotope ratio measurements.

The CO and CO_2 concentration variations obtained in the observation periods were shown in Figure1. CO_2 concentration had diurnal variations in the summer. In the winter, the temporal variations of CO_2 concentration were similar with those of CO concentration. The increments of CO and CO_2 concentration from the global background concentrations were defined as ΔCO and ΔCO_2, respectively. The contributions of combustion process and biogenic activity on CO_2 concentration were estimated by the ratios of ΔCO to ΔCO_2 and Keeling plot analyses of $\delta^{13}C$ and $\delta^{18}O$ (Figure2). The values of $\Delta CO/\Delta CO_2$ ratio were high and $\delta^{13}C$ were low in the winter, which shows the decrease of biogenic respiration and contribution of biomass burning and/or natural gas combustion.

This research was partly conducted under the framework of the GOSAT RA, and partly supported by GRENE-ei program.

Keywords: carbon dioxide, carbon monoxide, isotope ratio, ground base measurement, GOSAT-2

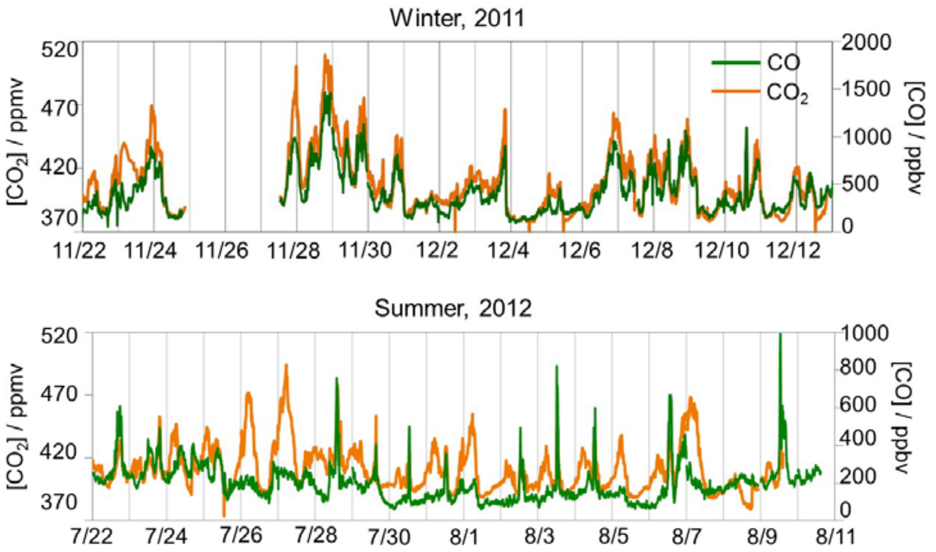

Figure 1 Temporal variations of CO and CO_2 concentration in Nagoya city

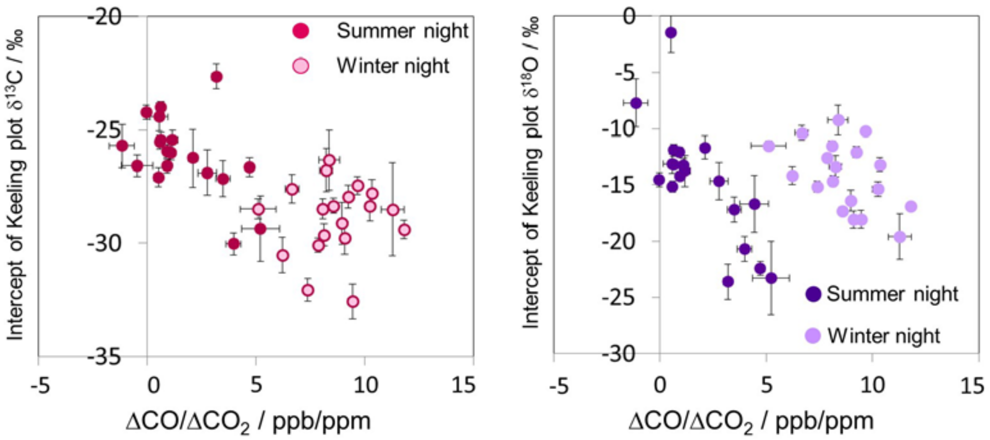

Figure 2 The relationship between $\Delta CO/\Delta CO_2$ and intercept of $\delta^{13}C$ and $\delta^{18}O$ according to Keeling plot analysis.

Are thermal infrared measurements of CO_2 from GOSAT and IASI over the Arctic Ocean in summer able to detect climatic change?

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The Arctic Ocean is a region where the impact of global change is detected on an annual basis by a wide variety of observations: buoys, research vessels and aircrafts. But the large area involved and the need of frequent sampling make polar orbiting satellites a prime source of observations for documenting the corresponding fast changes, especially in summer. Sun reflected measurements in the shortwave infrared (SWIR) region of the spectrum are not very sensitive because of the elevated solar zenith angle. In these conditions, thermal infrared (TIR) measurements using spectra collected by high spectral resolution nadir sounders are a good complement to document the high latitudes regions. In the present work the spectra acquired by the TANSO-FTS instrument on GOSAT and by the IASI instrument on the MetOp platforms have been used to test the retrieval capabilities of these Fourier transform spectrometers to retrieve the carbon dioxide column averaged mixing ratio XCO2 as well as the sea surface temperature (SST) used as an inversion diagnostic. Results for 3 observing periods in summer (July, August, September) and 6 years (2010 to 2015) have been obtained in the latitude range 68N to 82N over open water (no pack ice). The retrieved products have been analyzed from a climatologic point of view to assess inter-annual variability and trends of TIR derived XCO2 and SST zonal averages (3 summer months and 7 bins of 2° in latitude). Results will be described and compared with other sources of information. This type of study is important for preparing future satellite missions like IASI-NG (a follow-on of IASI) and GOSAT-2 (a follow-on of GOSAT). Some specific regional Arctic Ocean basins will be compared to the zonal climatologies.

Keywords: GOSAT, IASI, carbon dioxide, SST, retrieval, climatology

Verification of CH_4 Profile Retrievals from GOSAT Thermal Infrared Measurements

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In this study, we discuss the retrieval of methane from thermal infrared Earth radiance measurements at 1210-1310 cm^{-1} of the Fourier Transform Spectrometer (TANSO-FTS) aboard GOSAT. We infer simultaneously atmospheric abundances of CH_4, H_2O and N_2O, a spectral shift, and the skin temperature, with the temperature profile taken from ECMWF data and the emissivity calculated at high spectral resolution with the HSR code developed at the university of Wisconsin, which is based on MODIS measurements. To address retrieval biases, we have developed a radiometric correction based on atmospheric soundings over the ocean from the HIPPO aircraft campaigns of 2009 and 2010. No further a posteriori correction is applied. The retrieved CH_4 profiles are validated against a suite of measurements; the HIPPO aircraft campaign in 2011, the ACE satellite, and the AirCore campaign over Sodankyla. In addition, the profiles are verified with the MACC model runs. Finally, total columns are evaluated against measurements at nine TCCON sites. When applying the correction, the deviation in the profiles is significantly reduced by a factor of ~5 to 3% over the whole altitude range. At TCCON sites the uncertainty of the retrieved methane column is < 1%. Moreover, differences in night/day retrievals and over land/ocean crossings have significantly decreased.

Keywords: GOSAT, methane, profiles, retrieval, validation

Global Concentrations of CH_4 :

Retrieval and validation of Metop-A/IASI CH_4 columns

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The IASI nadir looking thermal infrared (TIR) sounder onboard MetOp-A enables the monitoring of atmospheric trace gases on a global scale. The IR team of BIRA-IASB retrieves profiles of atmospheric CH_4 from IASI spectra with the ASIMUT radiative transfer and retrieval software.

For this symposium we will present a quality assessment of the BIRA-IASB IASI CH_4 product and results of its validation with NDACC ground-based observations. We will show that 1 independent piece of information is retrieved in the altitude range 4-17 km for daytime and nighttime observations.

In addition, the usefulness of the IASI CH_4 product for source attribution and climate research will be highlighted.

Keywords: IASI, methane, retrieval, validation

Quantifying Lower Tropospheric Methane Concentrations Using GOSAT near-IR and TES thermal IR measurements.

Authors

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Abstract

Evaluating surface fluxes of methane using total column data requires models to accurately account for the transport and chemistry of methane in the free troposphere and stratosphere, thus reducing sensitivity to the underlying fluxes. Vertical profiles of methane have increased sensitivity to surface fluxes because lower tropospheric methane is more sensitive to surface fluxes than a total column and quantifying free tropospheric CH_4 concentrations helps to evaluate the impact of transport and chemistry uncertainties on estimated surface fluxes. Here we demonstrate new estimates of lower tropospheric CH_4 concentrations through the combination of free tropospheric methane measurements from the Aura Tropospheric Emission Spectrometer (TES) and XCH4 (dry-mole air fraction of methane) from the Greenhouse Gases Observing Satellite Thermal And Near Infrared for Carbon Observations (GOSAT TANSO, herein GOSAT for brevity). The calculated precision of these estimates ranges from 10 to 30 ppb for a monthly average on a 4x5 latitude / longitude degree grid making these data suitable for evaluating lower-tropospheric methane concentrations. Smoothing error is approximately 10 ppb or less. Comparisons between these data and the GEOS-Chem model demonstrate that these lower-tropospheric CH_4 estimates can resolve enhanced concentrations over flux regions that are challenging to resolve with total column measurements. We also use the GEOS-Chem model and surface measurements in background regions across a range of latitudes to determine that these lower-tropospheric estimates are biased low by approximately 65 ppb, with an accuracy of approximately 6 ppb (after removal of the bias) and an actual precision of approximately 30 ppb. This 6 ppb accuracy is consistent with the accuracy of TES and GOSAT methane retrievals.

Validation of the GOSAT TANSO-FTS TIR CH_4 vertical profile data product using CH_4 vertical profiles from MIPAS (ESA and IMK) and ACE-FTS

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The primary instrument on the Greenhouse gases Observing SATellite (GOSAT) is the Thermal And Near infrared Sensor for carbon Observations (TANSO) Fourier Transform Spectrometer (FTS). GOSAT is a joint venture by Japan's Ministry of the Environment (MOE), National Institute for Environmental Studies (NIES), and the Japan Aerospace Exploration Agency (JAXA). TANSO-FTS uses three short-wave infrared (SWIR) bands to retrieve total columns of CO_2 and CH_4 along its optical line-of-sight and one thermal infrared TIR channel to retrieve vertical profiles of CO_2 and CH_4 volume mixing ratios (VMRs) in the troposphere. We examine version 1 of the TANSO-FTS TIR CH_4 product by comparing co-located CH_4 VMR vertical profiles from two other remote sensing FTS systems: the CSA's Atmospheric Chemistry Experiment- (ACE-) FTS on SCISAT (version 3.5) and the ESA's Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) on Envisat (ESA ML2PP version 6 and IMK reduced-resolution versions V5R_CH_4_224 and V5R_CH_4_225). This work follows an initial inter-comparison study over the Arctic which incorporated a ground-based FTS at the Polar Environment Atmospheric Research Laboratory (PEARL) at Eureka, Canada (Holl et al. 2015), and focuses on tropospheric measurements made at middle and tropical latitudes between 2009 to 2013 (mid 2012 for MIPAS). The coincidence criteria imposed for CH_4 observations is that ACE-FTS and MIPAS measurements must be made within 12 hours and 500 km of a TANSO-FTS TIR measurement, and the ACE-FTS, IMK MIPAS and ESA MIPAS measurements must extend down to below 10, 12 and 12 km, respectively. For comparison, all three instruments are interpolated onto a fixed pressure grid, the ACE-FTS and MIPAS vertical profiles are smoothed using the TANSO-FTS averaging kernels, and measurements made on the pressure grid without overlapping coincident measurements are discarded. We present zonally-averaged mean CH_4 differences between each instrument and TANSO-FTS with and without smoothing, and examine their information content, sensitive altitude range, correlation, a priori dependence, and the variability within each data set. Initial results show that the TANSO-FTS vertical profiles agree with the ACE-FTS and both MIPAS vertical profiles within 4% below 20 km when smoothing is applied to the instruments with finer vertical resolution, but that the relative differences can increase to on the order of 25% when no smoothing is applied.

Global Methane Distributions Retrieved from IASI Observations in the Thermal and Short-Wave Infrared

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A continuous series of observations are planned by IASI on MetOp-A, -B and -C, followed by IASI-NG on MetOp-SG, covering the period 2007-2040. RAL has developed an optimal estimation scheme to retrieve global height-resolved information on methane from the thermal infrared (7.9 micron) band. The use of IASI thermal infrared observations produces methane data at relatively high spatial resolution, both day and night, over land and ocean. The retrieval scheme extracts two independent pieces of information on the profile, with sensitivity extending into the lower troposphere. The retrieval scheme has been extensively validated and shown to perform well in comparison with column-averages from both ground-based observations (TCCON) and from the satellite short-wave infrared sounder GOSAT; a paper is in submission to AMT (R.Siddans et al., 'Global height-resolved methane retrievals from IASI').

Exploiting the JASMIN-CEMS computational infrastructure at RAL, the IASI MetOp-A mission 2007-2015 has been processed and is available via the Centre for Environmental Data Analysis (www.ceda.ac.uk). The methane processor has also been integrated into our MetOp near real-time chain, producing data within 3 hours of IASI measurements being made.

Two major improvements to the methane processor are currently under development. Firstly, a pre-processor for the joint retrieval of temperature, humidity and surface spectral emissivity from IASI, MHS and AMSU on MetOp-A is being implemented in place of ECMWF forecast met fields and a surface emissivity climatology. This reduces retrieval errors caused by interpolation of the met forecast fields and improves on the emissivity prior estimate from the database. Secondly, we are investigating the potential to increase sensitivity to near-surface methane through the addition of the shortwave IR band at 3.9 microns.

In this paper, we illustrate the first 8-year IASI methane dataset in comparison to correlative and model data, the near real-time products and our latest processor improvements.

Keywords: IASI, methane, optimal estimation, retrieval

Continuous in-situ observation of methane 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). Satellite observations have suggested that the emissions of methane from in the paddy fields of north India have significant contribution to the methane emissions. But, there are many difficulties to conduct in-situ observations in such farmlands. The electric power are available for only 2-3 hours a day and there are bad influences on instruments due to rain, dust, bugs, etc. Thus, it is difficult to use expensive commercial instruments, which are typically operated under clean circumstances and stable electric power conditions. Therefore, we developed a low-cost measurement system of methane to use at rural and remote areas. We have used a LaserMethane (ANRITSU) instrument to measure the atmospheric concentrations of methane in India. The LaserMethane is an open-path laser spectroscopic instrument which can measure methane selectively by tunable diode laser absorption spectroscopy. We developed a solar power supply system, a data logging for continuous operation of the instrument at remote areas. We have conducted continuous in-situ observations of methane at Sonipat, Haryana in India which is located at north of Delhi since the end of 2014 using the developed system. We have also measured atmospheric methane concentrations at Sonipat using a vessel sampling method once a week. We presents the measurement results of one-year observation 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.

This research was partly conducted under the framework of the GOSAT RA, and partly supported by GRENE-ei program.

Keywords: India, paddy field, methane, in-situ measurements, seasonal variation, diurnal variation

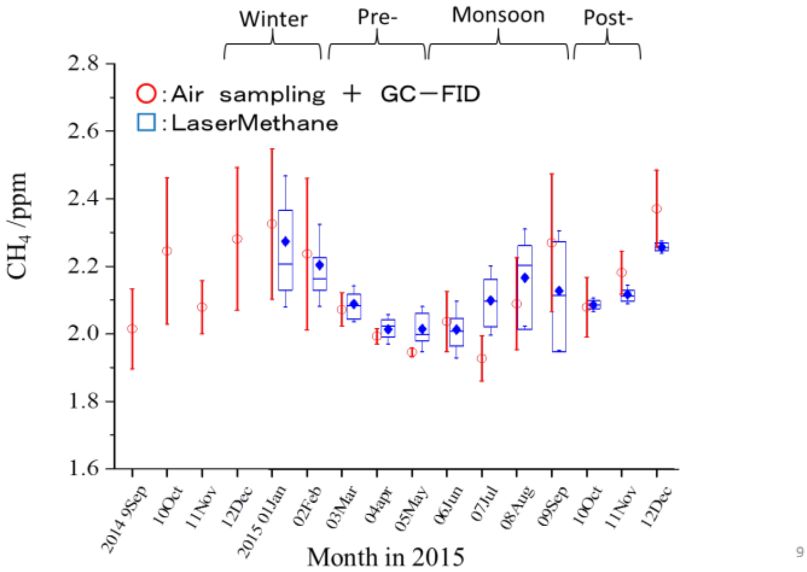

Fig. 1 Seasonal variations of methane concentration measured at the paddy field in North India

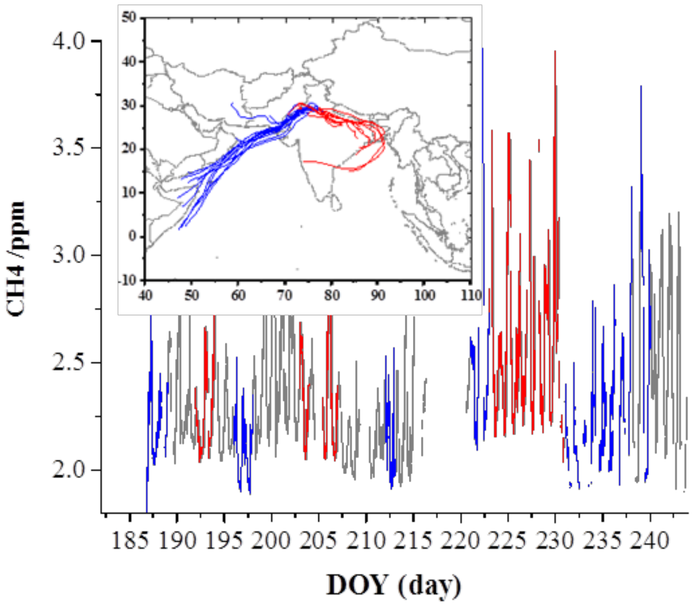

Fig. 2 Continuous in-site measurement results of methane concentrations in the monsoon season in 2015.

Characterization of biomass burning using CH_4 and CO_2 data observed by GOSAT

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In this study we focus on the ratio of CO_2 and CH_4 using the column averaged dry air mole fractions of atmospheric CO_2 and CH_4 (XCO_2 and XCH_4, respectively) observed by GOSAT/SWIR channel over the biomass burning regions to characterize the vegetation fuel and burning condition. We used the hotspot numbers from the MODIS Collection 5 active fire product as a proxy for the fire detection index, and defined some representative burning areas based on the hotspot numbers. Over Africa, Roberts et al. (Biogeosciences, 2009) reported the contrast of the months when active fires are observed in the Northern and Southern Hemisphere Africa (NHA and SHA); the peak of active fires are observed in December to February over NHA while May to July in SHA. As the GOSAT observation points are distributed sparsely, we accumulated the XCO_2 and XCH_4 in the relatively large areas (about 7 deg. in latitude times 20 deg. in longitudes). To avoid the effect of long-term trend we analyzed the data for each month during the period from 2009-2013. From the scatter plots of XCO_2 and XCH_4, the derived values of $\Delta XCH_4/\Delta XCO_2$ were between 0.3 and 0.5 x 10^{-2} for all areas and for most of the months, which are approximately corresponding to the estimate for the vegetation categories of Savanna and Grassland (0.37 x 10^{-2}) or Woodland (0.74 x10^{-2}) (Table 5 of van der Werf et al., 2010). Preliminary comparison between NHA and SHA showed somewhat higher values of $\Delta XCH_4/\Delta XCO_2$ in the NHA than those in SHA, which may suggest the difference of vegetation fuel or burning condition in those areas. Further detailed including analysis over Asia will be presented.

Keywords: GOSAT, biomass burning, CH_4, CO_2

Atmospheric CH_4 and CO_2 enhancements and biomass burning emission ratios derived from GOSAT observations of the 2015 Indonesian fire plumes

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Here, for the first time, we use satellite observations of CH_4 and CO_2 from the Greenhouse gases Observing SATellite (GOSAT) made in large scale plumes from the 2015 El Nino-driven Indonesian fires to probe aspects of their chemical composition. We demonstrate significant modifications in the concentration of these species in the regional atmosphere around Indonesia, due to the fire emissions.

We determine the CH_4/CO_2 fire emission ratio for the entire 2-month period of the most extreme burning (September- October 2015), and also for individual shorter periods where the fire activity temporarily peaks. We demonstrate that the overall CH_4/CO_2 emission ratio for fires occurring in Indonesia over this time is 6.2 ppb/ppm. This is higher than that found over both the Amazon (5.1 ppb/ppm) and southern Africa (4.4 ppb/ppm), consistent with the Indonesian fires being characterised by an increased amount of smouldering combustion due to the large amount of organic soil (peat) burning involved. We find the range of our satellite-derived Indonesian ERs to be relatively closely matched to that of a series of ground-based sampling measurements made at the height of the fire event.

The ability to determine large-scale ERs from satellite data allows the combustion behaviour of large regions of burning to be characterised and understood in a way not possible with ground-based studies. We therefore believe the method demonstrated here provides an important tool for characterising biomass burning emissions, and that the GHG emission ratios derived for the first time for these large-scale Indonesian fire plumes during an El Nino event, points the way to more routinely assessing spatio-temporal variations in biomass burning emission ratios using future satellite missions that will have more complete spatial sampling than GOSAT, and that will enable the contributions of these fires to the regional atmospheric chemistry and climate to be better understood.

Keywords: emission ratio, fires, El Nino, GOSAT, carbon dioxide, methane

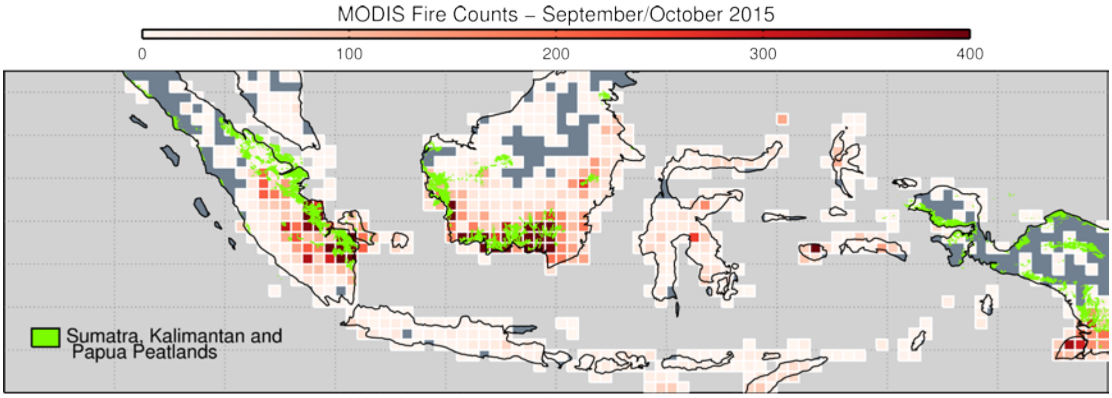

Figure 1: MODIS fire counts for September/October 2015 over the Indonesia, gridded into 0.5°x0.5° boxes. Also overlaid are the locations of known peatlands in Sumatra (left), Kalimantan (centre) and Papua (right).

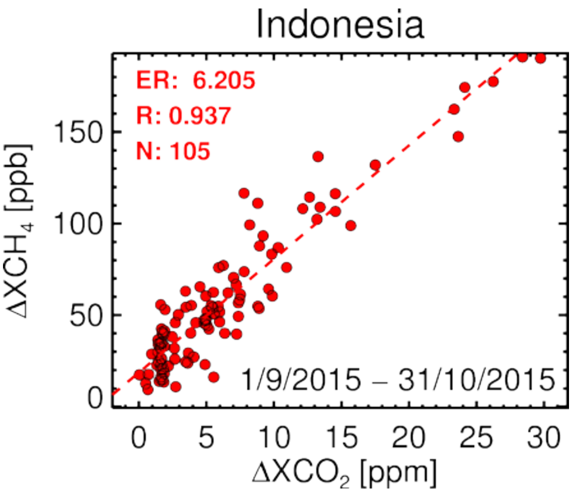

Figure 2: Scatterplot of GOSAT-derived ΔXCH_4 vs ΔXCO_2 values for large-scale fire plumes seen over Indonesia from 1st September 2015 to 31st October 2015, calculated as the total column difference between the 'fire affected' and corresponding clear 'background' TANSO-FTS soundings. The CH_4/CO_2 emission ratio, ER (ppb/ppm), is calculated from the gradient of a linear best fit, shown as the dashed line. Also shown are the correlation coefficient, R and the number of soundings, N.

Mitigating model biases and constraining North American methane emissions using weak constraint 4D-Var

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Regional inverse modeling provides a computationally efficient means of obtaining high-resolution methane emission estimates, which are of great value, especially for quantifying local anthropogenic emissions. However, quantifying high-resolution emission estimates is particularly challenging due to their relatively weak signature in the atmosphere. These regional inversion analyses are also sensitive to biases in boundary conditions because the bias in background methane entering the region directly projects onto emissions.

In this work, we employ the GEOS-Chem four-dimensional variational (4D-Var) data assimilation system to conduct a series of observing system simulation experiments (OSSEs) using surface, aircraft, and satellite data to investigate the robustness of high-resolution North American methane emission estimates. In particular, we utilize the weak constraint 4D-Var capability recently implemented in GEOS-Chem, which accounts for model errors, together with the vertical profile information provided by NOAA aircraft measurements over North America, to mitigate the impact of biases in the inflow of methane into the region. We perform inversion analyses using pseudo aircraft and surface methane flask measurements over North America with an imposed extreme bias in model methane transport, a priori emissions and initial concentrations, and show that North American emissions can be recovered to within 10% of “true” emissions. We also explore the sensitivity of the inversion results to the temporal resolution of the aircraft measurements. We find that using only three aircraft profiles per months at multiple locations over North America together with surface in situ measurements, we are able to better recover regional emissions compared to the case of using space-based, column-averaged dry-air mole fractions of methane.

Keywords: regional inverse modeling, methane emissions, boundary conditions, GEOS-Chem, weak constraint 4D-Var, aircraft observations, satellite observations

THE GOSAT COMEX EXPERIMENT: VALIDATION OF GOSAT-DIRECTLY DERIVED FLUXES

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Satellites hold the promise of monitoring greenhouse gases (GHGs) - methane (CH_4) and carbon dioxide (CO_2) - emissions globally from continental to facility length-scales; however, validation is key to acceptance. We report on fusion of airborne, surface, and GOSAT data supported by mesoscale modeling to derive emissions directly for three adjacent active oil fields near Bakersfield, CA where topography causes complex winds, including explicit uncertainty assessment. Based on 40,390 km of surface survey data, Bakersfield area CH_4 anomaly were the largest in Southern California.

Annual emissions were 45±12 Gg CH_4 (triple inventories) and 5.0±4.8 Tg CO_2 for the oil fields based on 8 datasets spanning approximately one year. On 11 February 2015, there was excellent agreement between the GOSAT, directly-derived flux of 58 kton yr^{-1} and surface–derived in situ fluxes of 44 and 85 kton yr^{-1} from observations bracketing GOSAT acquisitions in time. The longitudinal derived fluxes showed an exponential decrease (R^2=0.99) with a 478-day timescale. Persistent CH_4 plumes were tracked during 14 surveys including very strong plumes during an initial period when drilling rigs were observed, which decreased with a timescale of ~100 days, suggesting that “super-emitter” emissions (and their mitigation) only comprise a small fraction of overall emissions. Similar trends across the field indicate geological connectivity analogous to natural seepage.

Keywords: GOSAT, methane, flux, production, column validation

Surface CO_2 and CH_4 fluxes simultaneously inferred from proxy GOSAT XCH4:XCO2 retrievals: Trend and Inter-annual variations

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The Japanese Greenhouse gases Observing SATellite (GOSAT) has provided continual measurements of atmospheric CO_2 and CH_4 columns since it was launched in 2009. We use an ensemble Kalman Filter (EnKF) to infer simultaneously regional CO_2 and CH_4 fluxes from 2009 to 2015 by assimilating proxy GOSAT XCH4:XCO2 retrievals and NOAA in situ data, building on previous work from our group. The proxy retrieval method fits the absorption spectrum by CO_2 and CH_4 gases in nearby spectral windows (at 1.65 μm and 1.61 μm). So their ratio is less sensitivity to fitting artefacts common to both gases (e.g. aerosol and clouds), resulting in more useful retrievals over regions such as Tropical South America, which currently represent the largest uncertainties in our current understanding of the global carbon cycle.

We find that both the CO_2 and CH_4 fluxes inferred from the proxy retrievals have generally much lower posterior uncertainties than inversions using only the full physics GOSAT retrievals of XCO2 and XCH4 or only using the NOAA in situ data. We find particular improvements over regions such as tropical land regions, where the full physics retrievals has coarse coverage because of frequent cloud presence or high aerosol loading. We find that over Eurasia and the tropics, CO_2 and CH_4 flux estimates inferred from the proxy data have different seasonal cycles and inter-annual variations compared with the emissions inferred from in situ data. We discuss the correlation between the inter-annual variation of the resulting CO_2 and CH_4 fluxes over different regions, with the observed El-Nino events, in particularly for 2015.

Keywords: GOSAT, proxy retrieval, inversion, carbon dioxide, methane.

Quantifying Regional CO_2 Flux Estimates Using OCO-2 Data

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Inverse modeling of regional CO_2 sources and sinks is sensitive to the observational coverage of the observing network. The Greenhouse gases Observing SATellite (GOSAT) provided greater observational coverage of atmospheric CO_2 than the surface flask network, and the recently available data from the Orbiting Carbon Observatory (OCO-2) significantly expand the spatio-temporal coverage of space-based observations of atmospheric CO_2 compared to GOSAT. Here we use column-averaged dry-air mole fractions of CO_2 (XCO_2) from OCO-2, together with the 4-dimensional variational (4D-Var) data assimilation system in the GEOS-Chem model, to quantify regional fluxes of atmospheric CO_2 from October 2014 to September 2015. We compare the constraints on the regional CO_2 flux estimates inferred from OCO-2 data with those obtained from GOSAT and the surface flask network. We also assess the potential impact of latitude-dependent biases in the OCO-2 data on the CO_2 flux estimates.

Keywords: OCO-2, GOSAT, carbon dioxide, assimilation, flux inversion

Estimating 2015 CO_2 fluxes with OCO-2 observations

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The newly launched NASA Orbiting Carbon Observatory-2 (OCO-2, launched in July 2014) provides direct and global atmospheric column CO_2 observations (X_{CO2}). In this study, we estimate terrestrial biosphere fluxes for the time period of September 2014 to Dec 2015 assimilating OCO-2 X_{CO2} observations into a top-down flux inversion model. The time period spans one of the strongest El Nino events in record. We will use OCO-2 observed Solar Induced Fluorescence (SIF), which is a product of photosynthesis, and carbon monoxide observations from Measurements of Pollution in the Troposphere (MOPITT) to attribute the net CO_2 fluxes constrained by X_{CO2} to gross primary production (GPP) and fire burning emissions. We will show the impact of 2015-2016 El Nino on the regional flux anomaly by comparing the fluxes constrained by OCO-2 to the 2010-2014 fluxes constrained by GOSAT observations. The climate variable, such as precipitation, will also be analyzed to understand the relationship between climate variable and the carbon exchange between land and atmosphere.

Keywords: OCO-2, ElNino, GOSAT, CO_2, GPP, MOPITT

Orbiting carbon observatory (OCO-2) tracks 2 Giga tons of carbon release to the atmosphere during the El Nino 2015

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In 2015, the powerful El Nino events is likely to have large impact on the Earth's natural climate system, which in turn affect the terrestrial ecosystem. Here we use column-averaged CO_2 dry mole fraction (X_{CO2}) estimates from the Orbiting Carbon Observatory-2 (OCO-2) satellite from September 2014 until February 2016 to show that the 2015 El Nino event led to excess release of CO_2 by about 2 PgC (1 Pg = 10^15 g) to the atmosphere. A global atmospheric chemistry-transport model (i.e., JAMSTEC's ACTM) shows that the excess CO_2 release is largely caused by biomass burning. The ACTM simulations are performed for three combinations of terrestrial and oceanic CO_2 fluxes: CYC64 (Patra et al., 2011), IAV84 (Thompson et al., 2016) and IAV84+GFAS (Kaiser et al., 2012). The X_{CO2} growth rates are slightly overestimated by ACTM_CYC64, while the growth rate is slightly underestimated by ACTM_IAV84 in comparison with OCO-2 observations. All the ACTM simulations use same emissions from fossil fuel consumption and cement production (~10 PgC/yr), but different annual total land and ocean fluxes (-2.80 and -6.29 PgC/yr, which correspond to the inversion period of 2008 and 2011, respectively, for CYC64 and IAV84 cases). Given that 2011 was a strong La Nina year, it is expected that the X_{CO2} growth rate is underestimated by ACTM_IAV84. Thus we have added emissions due to forest fires and biomass burning from GFAS during the period of our simulation with IAV84, which then quite accurately simulate the observed X_{CO2} growth rate during the whole period of OCO-2 measurements. Using the 3 cases of ACTM simulated in comparison with OCO-2 measurements, we conclude that the global fire-related emissions by GFAS of about 2.0 PgC/yr, and its geographical distribution is in good agreement with the El Nino years of 2015.

Keywords: OCO-2, carbon dioxide, ACTM, transport modeling

Multi-model Flux Inversion Comparison using OCO-2 Data

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Since the launch of the Orbiting Carbon Observatory-2 satellite in July 2014, data has been accumulating from its midday local time orbit, using both nadir and glint observational geometries. In September of 2015, the OCO-2 Algorithm Team released a bias corrected L2 product for use by the flux inversion community. This "lite" product contains bias corrections to remove non-physical small scale variability (e.g. footprint to footprint) as well as from comparisons with TCCON, multi-model ensemble comparisons, and other retrieval derived metrics.

Flux inversion modelers from various institutions around the world have assimilated OCO-2 X_{CO2} with different prior emissions estimates as well as other assumptions, with varying results. Some large scale features between the different inversions are similar, such as the apparent large source in South America due to a high latitude glint bias. In March of 2016, it was determined that a multi-model flux intercomparison was necessary to proceed with determining the best use of the OCO-2 data.

In this presentation, we discuss the findings of different groups and conclusions about the OCO-2 data drawn from the commonalities and differences between the large scale and regional results, as well as some inferences that can be drawn about the retrieval biases from these patterns, and what sorts of bias correction might be useful for any future reprocessing.

Keywords: OCO-2, carbon dioxide, retrieval, validation, atmospheric inversion, surface flux

Influence of El Nino on atmospheric CO_2: Findings from the Orbiting Carbon Observatory-2 (OCO-2) Mission

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The El Nino Southern Oscillation (ENSO) is the most important mode of tropical climate variability on interannual to decadal time scales. Correlations between atmospheric CO_2 growth rate and ENSO activity have been well known within the carbon cycle community; however, the magnitude of this correlation, the contribution from tropical terrestrial vs. oceanic flux components, and the causal mechanisms, are poorly constrained in space and time. The launch of OCO-2 has been rather timely given the development of strong ENSO conditions over the equatorial Pacific Ocean in 2015. In this presentation, we will discuss how the high-density observations from OCO-2 have provided us with a novel dataset to resolve the linkages between ENSO and atmospheric CO_2. Preliminary results indicate positive correlation between atmospheric X_{CO2} anomalies and SST anomalies across specific sectors of the equatorial Pacific Ocean, with the X_{CO2} anomalies lagging the SST anomalies by timescales of ~ 4-6 weeks. Using a suite of model simulations of air-sea fluxes and atmospheric transport, in situ observations of ΔpCO_2 from NOAA's Tropical Atmosphere Ocean (TAO) project and auxiliary information from additional remote-sensing missions, this study attempts to attribute the mechanisms responsible for the magnitude and phasing of the observed ENSO-CO_2 correlations. We expect this analysis to improve our understanding of the marine vs. terrestrial partitioning of tropical carbon fluxes during El Nino conditions, their relative contributions to the global atmospheric CO_2 growth rate, and consequently provide important clues into the sensitivity of the carbon cycle to climate forcing on interannual time scales.

Keywords: OCO-2, ENSO, tropical inter-annual variability of CO_2, partitioning of tropical carbon fluxes

TROPOMI is ready for launch:

Pre-flight performance and calibration measurements

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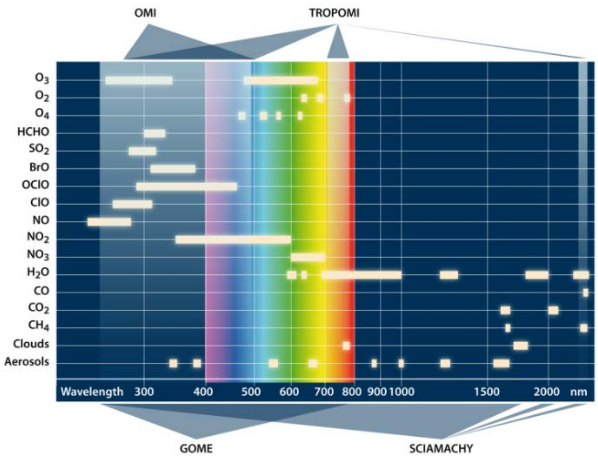
(3) Netherlands Institute for Space Research (SRON)

TROPOMI is ready for launch! After years of design, development, breadboarding, integration, testing and calibration, after lots of successes as well as some setbacks, TROPOMI is ready for its transition to the next phase. That is the transition from engineering to science. In this paper we describe one of the final steps in the engineering phase with a focus on the approach of pre-flight instrument performance testing and calibration.

TROPOMI follows in a tradition of European low Earth orbit instruments (e.g. GOME, SCIAMACHY, OMI): they all use solar backscattered radiation in the UV-VIS-NIR-SWIR wavelengths to measure many atmospheric constituents (like O_3, NO_2, SO_2, CO, CH_4 and many more), using a broad view that enables mapping of the entire globe within one (or a few) days. TROPOMI is the only instrument onboard ESA's Sentinel 5 Precursor satellite. Despite its precursor status, it is clearly the next generation instrument, as its sensitivity is much improved w.r.t. its predecessors, while at the same time the ground sampling is much smaller. This allows for much acurate measurements of these atmospheric constituents at a finer spatial grid.



From December 2014 until May 2015 the TROPOMI instrument underwent performance and calibration testing, in a single measurement campaign. Measurements were performed 24/7 with a very high measurement efficiency, and as a result, nearly all of the planned measurements could be performed. This efficiency was achieved a.o. by close cooperation between test engineers, operators, science data processing and calibration management. In case of unforeseen events, quick decisions could thus be made.

In spite of the limited time available for the on-ground measurement campaign the TROPOMI performance verification and calibration campaign is considered by all parties as successful. We can now safely say that TROPOMI is ready for launch and for subsequent studies of the Earth's atmosphere.

The Pre-Launch Status of TanSat Mission

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The Chinese Carbon Dioxide Observation Satellite (TanSat), the first scientific experimental CO_2 satellite of China, is going into the pre-launch phase and is scheduled to be launched in the end of 2016. The Carbon Dioxide Spectrometer (CDS) has been optimized during the pre-flight test that quantifies the geometric, radiometric and spectroscopic parameters. It shows the Instrument Line Shape (ILS) and Signal Noise Ratio (SNR) meet the design requirements. The observatory integration and test of satellite platform and payloads are now being completed.

The XCO2 retrieval algorithm has been fully evaluated on its application to GOSAT data, and validated with TCCON measurement, its product achieves a 1.5 ppm precision. A Chinese carbon cycle data assimilation system Tan-Tracker is developed with a dual-pass data-assimilation system in which both CO_2 concentrations and CO_2 fluxes are simultaneously assimilated from atmospheric observations. The post-launch activities of early operations, on-orbit calibration operations, data validation and applications have been scheduled and the TanSat products will be delivered to the scientific community and common users.

Keywords: TanSat, carbon dioxide, retrieval, validation

The Status of NIES GOSAT-2 Peoject and

NIES Satellite Observation Center

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A successor of GOSAT, GOSAT-2, is jointly promoted by Ministry of the Environment, Japan Aerospace Exploration Agency, and National Institute for Environmental Studies (NIES), and will be launched in FY2017. GOSAT-2 will measure not only carbon dioxide and methane but also carbon monoxide by its improved Fourier transform spectrometer, FTS-2. Air pollution is also one of targets of GOSAT-2.

NIES GOSAT-2 Project is responsible for generation, validation, archive, and distribution of GOSAT-2 higher level products. G2DPS (GOSAT-2 Data Processing System) is a system for GOSAT-2 data processing, and currently being designed by contractors. It will receive GOSAT-2 Level 1 products from JAXA, and generate and distribute Level 2 and other higher level products. In addition, a system named GOSAT Air Pollution Watch is being developed. It is a rapid GOSAT and GOSAT-2 data processing / distribution system for urban air pollution monitoring caused mainly by particulate matters. Joint research projects related to GOSAT Air Pollution Watch with several developing countries are ongoing.

As for validation of GOSAT-2 gas column amount products such as XCO_2 and XCH_4, TCCON (Total Carbon Column Observing Network) will be a major source of validation data. A new TCCON station in the northern Philippines will be established as one of activities of NIES GOSAT-2 Project.

In April 2016, NIES established a new organization, Satellite Observation Center (SOC), for long term operations of multiple satellite missions. SOC is responsible for various aspects of NIES GOSAT and GOSAT-2 projects including operational data processing, maintenance of computer and storage systems, and outreach activities. GOSAT-3 will also be studied under SOC.

Keywords: GOSAT-2, G2DPS, GOSAT Air Pollution Watch, TCCON, GOSAT-3

The OCO-3 Mission : Overview of Science Objectives and Status

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The Orbiting Carbon Observatory 3 (OCO-3) will investigate important questions about the distribution of carbon dioxide on Earth as it relates to growing urban populations and changing patterns of fossil fuel combustion. OCO-3 will explore, for the first time, daily variations in the release and uptake of carbon dioxide by plants and trees in the major tropical rainforests of South America, Africa, and Southeast Asia, the largest stores of aboveground carbon on our planet. OCO-3 is planned to be installed on the International Space Station in late 2018.

The low-inclination ISS orbit lets OCO-3 sample the tropics and sub-tropics across the full range of daylight hours with dense observations at northern and southern mid-latitudes (+/- 52º). At the same time, OCO-3 will also collect measurements of solar-induced chlorophyll fluorescence (SIF) over these areas. The combination of these dense, high precision CO_2 and SIF measurements provides continuity of data for global flux estimates as well as a unique opportunity to address key deficiencies in our understanding of the global carbon cycle. The instrument utilizes an agile, 2-axis pointing mechanism (PMA), providing the capability to look towards the bright reflection from the ocean and validation targets.

The PMA also allows for a snapshot mapping mode to collect dense datasets over 100km by 100km areas. Measurements over urban centers could aid in making estimates of fossil fuel CO_2 emissions. This is critical because the largest urban areas (25 megacities) account for 75% of the global total fossil fuel CO_2 emissions, and rapid growth (> 10% per year) is expected in developing regions over the coming 10 years. Similarly, the snapshot mapping mode can be used to sample regions of interest for the terrestrial carbon cycle. For example, snapshot maps of 100km by 100km could be gathered in the Amazon or key agricultural regions, in collaboration with other instruments on the ISS.

Keywords: OCO-3, carbon dioxide, anthropogenic emissions, terrestrial carbon cycle

An introduction to MicroCarb, first European program for CO_2 monitoring.

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(2) Laboratoire des Sciences du Climat et de l'Environnement (LSCE).

Decision to conduct the MicroCarb program has been announced by the French government in December 2015, in the frame of the COP-21. MicroCarb is thus the first European mission dedicated to atmospheric Carbon dioxyde monitoring from space. MicroCarb is a sampling mission which relies on original techniques in order to make accurate measurements from an affordable micro satellite, and targets a launch in 2020. It will then provide continuity of monitoring data and also contribute to prepare and develop the skills which are necessary for future operational missions.

The presentation will give a general introduction to the program. It will describe the objectives, provide the main characteristics and present the performances and the main elements associated with the organization and the initiated development and finally put light on the status of the program.

A second presentation (Author: D. Pradines) is proposed as complementary and will provide a technical insight of the program through system specification and characteristics and elements of the design.

Keywords: MicroCarb, carbon dioxide, microsatellite

Technical insight into MicroCarb, first European program for CO_2 monitoring

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(1) Centre National d'Etude Spatiales (CNES)
(2) Laboratoire des Sciences du Climat et de l'Environnement (LSCE).

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After a first presentation (Author: F. Buisson) giving a general introduction to the program (objectives, organization, overall characteristics and performances, current status), this one will focus on technical features: quick insight into optical design, trade-off between different candidate spectral bands, pointing modes specification and capabilities aiming at optimizing the mission contribution to CO_2 fluxes knowledge, instrument and system performances, calibration strategy, satellite flexibility to different orbits and launcher…

A poster (Author: D. Jouglet) will be dedicated to CO_2 and CH_4 concentrations and fluxes performances expected with MicroCarb updated concept.

Keywords: MicroCarb, carbon dioxide, microsatellite

Advances in Pulsed Lidar Measurements of CO_2 Column Concentrations in Airborne Campaigns and for Space

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We report progress in demonstrating a pulsed, multiple-wavelength integrated path differential absorption lidar technique for measuring the tropospheric CO_2 concentrations. The lidar measures the atmospheric backscatter profiles and shape of the 1572.33 nm CO_2 absorption line by using fixed wavelength samples distributed across the line. Airborne measurements have used both 30 and 15 wavelength samples. Post-flight analysis estimates the lidar range and pulse energies at each wavelength 10 times per second. The retrievals solve for the optimum CO_2 absorption line shape and the column average CO_2 concentrations using radiative transfer calculations, the aircraft altitude, range to the scattering surface, and the atmospheric conditions. We compare these to CO_2 concentrations sampled by in-situ sensors.

In recent campaigns the lidar used a new step-locked laser diode source, a new HgCdTe APD detector in the receiver. During August and September 2014 the ASCENDS campaign utilized the NASA DC-8 aircraft and flew over the California Central Valley, the California coastal redwood forest, desert areas, and above growing crops in Iowa. Analyses show the retrievals of lidar range and CO_2 column absorption, and mixing ratio worked well when measuring over variable topography and through thin clouds and aerosols. The retrievals clearly show the decrease in CO_2 concentration over growing cropland. Airborne lidar measurements of horizontal gradients of CO_2 concentrations across Nevada, Colorado and Nebraska showed good agreement with those from a model of CO_2 flux and transport (PCTM). In several flights the agreement of the lidar with the column average concentration was < 1ppm, with standard deviation of 0.9 ppm. Two additional flights were made in February 2016 using a larger laser spot size and an optimized receiver. These improved the sensitivity x3, and the retrievals show 0.7 ppm precision over the desert in 1 second averaging time. A summary of these results will be presented, along with on-going developments for a space version.

Keywords: carbon dioxide, lidar, retrievals, ASCENDS

Updated Performance Simulations for a Space-Based CO_2 Lidar Mission

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In 2010 we published a set of performance simulations for a planned space-based CO_2 lidar mission (Kawa et al., Tellus B, 62, 759–769). The tested mission concept corresponds to the Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) recommended by the US National Academy of Sciences' 2007 Decadal Survey. The study was based on a realistic projection of the lidar instrument hardware performance, radiative transfer calculations, and a simplified two-wavelength retrieval algorithm. XCO2 errors were calculated globally using a consistent set of modeled and measured data: model CO_2 atmosphere constrained by assimilated meteorology, cloud and aerosol attenuation from CALIPSO, and surface reflectance from MODIS plus analyzed winds over ocean. The results for an instrument point design based on reasonable assumptions for technology development at the time showed global XCO2 random errors with an RMSE of about 1.2 ppmv. This would satisfy ASCENDS measurement requirements and significantly enhance our ability to address carbon cycle science questions. Whether the measurements would, however, be precise enough to discern small signals such as the XCO2 difference between dawn and dusk sampling, differencing retrievals to cloud tops and the surface, or resolving small-scale variability was questionable.

During the past 6 years the laser CO_2 instrument concept, retrieval approaches, and measurement technologies have matured significantly, driven by lidar technology improvements and by analysis of measurements from airborne simulators. We have recently updated the performance simulations to match the latest developments. These results show lower errors, better spatial resolution, and more information content for global XCO2 data. Here we will present the updated calculations, discuss implications for enhanced targeting of key science objectives, and compare to actual observations from GOSAT and OCO-2. The findings further affirm the expected benefits of ASCENDS for carbon cycle science.

Keywords: ASCENDS, satellite, carbon dioxide, uncertainty analysis

Optical Depth Distribution and Surface Elevation Variability Derived from CALIPSO Lidar Measurements

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Atmospheric carbon dioxide (CO_2) is one of the major greenhouse gases in the Earth's climate system. The CO_2 concentration in the atmosphere has been significantly increased over the last 150 years, due mainly to anthropogenic activities. Comprehensive measurements of global atmospheric CO_2 distributions are urgently needed to develop a more complete understanding of CO_2 sources and sinks. Because of the importance of the atmospheric CO_2 measurements, satellite missions with passive sensors such as GOSAT and OCO-2 have been launched, and those with active sensors like Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) using an integrated path differential absorption (IPDA) lidar are being studied. The required accuracy and precision for the column-integrated CO_2 mixing ratios (XCO2) is high, within 1.0 ppm or approximately 0.26%, which calls for unbiased CO_2 measurements and accurate determinations of the path length. The presence of clouds and aerosols can make the measurement complicated, especially for passive instruments. The heterogeneity generated by the surface elevation changes within the field of view of the sensors and the grid boxes of averaged values of atmospheric CO_2 would also cause significant uncertainties in XCO2 estimates if the path length is not accurately known. Thus, it is required to study the cloud and aerosol distributions as well as the surface elevation variability in assessing the performance of the CO_2 measurements from both active and passive instruments.

The CALIPSO lidar has acquired nearly 10 years of global measurement data. It provides a great opportunity to study the global distribution of clouds and aerosols as well as the statistics of the surface elevation variations. In this study we have analyzed one year (2008) of the CALIPSO Level 2 data to derive the global occurrence of aerosols and optically thin clouds. The results show that clear sky does not occur as frequently as expected. The global average occurrence is only about 8% for very clean air with columnar OD at 532 nm < 0.01. It increases to ~29% when OD < 0.1, and ~42% when OD < 0.3, which is close the clear atmospheric threshold from regular passive remote sensing instruments. This calls for a capability to make precise retrievals in the presence of relatively dense aerosols or thin clouds.

One year (2008) of surface elevation data derived from the CALIPSO lidar has also been used in the assessment of surface elevation variability for passive sensor observations. It is shown that the variability of the surface elevation generally increases with increases in footprint size and surface elevation. For a footprint of 1-2 km typical for passive sensors, the mean standard deviation is 5-10 meters when elevation < 1 km and can reach 100 meters as the elevation increases. The occurrence frequency for a standard deviation > 10 m is greater than 20%, which can cause significant biases in the CO_2 retrieval if the presence of the cloud and/or aerosol cannot be identified and corrected.

With ranging capability, the ASCENDS lidar system supported by NASA will reliably measure CO_2 even in the presence of multiple backscatter targets (surface and transparent clouds) as shown during the experiments of recent airborne system demonstrations. However, it is very challenging for passive satellites to make reliable retrievals in the multiple-layer target case, because of the lack of path length information.

Keywords: ASCENDS, carbon dioxide, CALIPSO, optically thin clouds, surface elevation

Green LITE over Paris: A New Approach to Urban Scale Monitoring of Greenhouse Gas

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In 2015 Harris Corporation and its partners at Atmospheric and Environmental Research Inc. deployed a horizontal mapping system of the 2D variations in atmospheric CO_2 concentration on a horizontal plane over ~30 square km in the north-west quadrant of Paris, France. The Greenhouse gas Laser Imaging Tomography Experiment (GreenLITE) system utilizes the IMCW laser absorption spectroscopy method developed for an airborne demonstration unit for the ASCENDS Mission, currently a primary instrument on the NASA Earth Venture Suborbital mission ACT-America. This unique implementation was initially developed for the Department of Energy for monitoring large area ground carbon sequestration sites. The system consists of two scanning transceivers separated in space, each illuminating a series of reflectors surrounding the area of interest to form a crosshatched pattern. Each line-of-sight path between the transceiver and reflector measures the differential transmission over ~5 km path. The differential transmission along with local weather data are utilized in a cloud-based computing architecture to retrieve the dry air mixing ratio of the gas being measured.
The current system is measuring CO_2 every 10 seconds along two of 30 chords and generating estimates of the 2D spatial distribution of CO_2 over the city of Paris every 10 minutes. The data is displayed in real-time via a web-based interface. The system is being evaluated against one in situ station and the CHIMERE atmospheric transport model at 2 km resolution prescribed with fluxes from inventories for fossil CO_2 emissions and from one vegetation model for natural fluxes. GreenLITE offers complimentary measurements to current methods of calibration for GHG satellites by offering a connection between the horizontal variability within the boundary layer and the integrated vertical column measurements. A system capable of measuring both CO_2 and CH_4 is under development, with the desire to deploy to a US city in early 2017.

Keywords: carbon dioxide, methane, urban monitoring reporting and verification, spatial mapping of GHG, Calibration

Radiometric and spectral sizing for future CO_2 observing space missions

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Space-borne measurements of dry air column averaged mixing ratios of carbon dioxide (XCO2) have been demonstrated to date by three satellite missions (SCIAMACHY, GOSAT and OCO-2), and new missions are under development (TANSAT, GOSAT-2, MicroCarb, OCO-3). The observational approach for all these missions is based on passive sensing of TOA spectral radiance, and implemented either by grating spectrometers (in push-broom mode) or Fourier Transform spectrometers. The individual missions address different spatial domains, and also differ significantly in instrumental parameters, such as signal-to-noise ratio (SNR), spectral resolving power and spectral range. While the SWIR bands of the pioneering SCIAMACHY instrument were operating at relatively coarse spatial and spectral resolution, the current generation of dedicated greenhouse gas observing missions operate at significantly higher resolving power and spatial sampling.

More recently, the feasibility studies for ESA's Earth Explorer candidate mission CarbonSat resulted in an instrument concept with relatively low spectral resolution and high SNR, as compared to other current (GOSAT, OCO-2) and planned missions (TANSAT, MiroCarb). The radiometric and spectral sizing of CarbonSat was partly driven by the targeted imaging mode at high spatial sampling (2 km x 3 km) and wide swath (240 km). While the chosen configuration was shown to yield accurate retrievals of XCO2 (of ~1 ppm), the detailed error budgets from performance analyses indicated a high sensitivity w.r.t. instrumental effects, such as straylight and ISRF distortion. Although these are regarded as manageable by state-of-the-art instrumental design and correction algorithms, the optimization of greenhouse gas imaging sensors w.r.t. instrumental errors remains a topic to be studied in light of challenging new mission objectives, such as the separation of biogenic and anthropogenic emission sources.

Starting from the CarbonSat concepts the presentation will compare past and future greenhouse gas monitoring missions in terms of their instrumental parameters. It will also present results from retrieval simulations investigating the sensitivity of XCO2 retrieval precision to realistic instrumental effects, such as straylight, polarization sensitivity and non-uniform scenes. The implications regarding an optimized instrument concept for space-borne greenhouse gas imaging will be discussed.

Keywords: CarbonSat, instrument parameters, spectral resolution, retrieval, simulation

The Geo Carb Mission

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With
Robert Chatfield (Ames Research Center), Randy Kawa (Goddard Space Flight Center), Susan Kulawik (Ames Research Center), Jack Kumer (Lockheed Martin Space Systems), Dennis O'brien, Chris O'Dell (Colorado State University), Igor Polonsky (Atmospheric and Environmental Research)

This paper presents a discussion of an instrument and space mission (GeoCARB) that would provide measurements of atmospheric carbon dioxide (CO_2), methane (CH_4), and carbon monoxide (CO) from geostationary orbit. The GeoCARB mission would deliver multiple daily maps of column integrated mixing ratios of CO_2, CH_4, and CO over the observed landmasses at a spatial resolution of roughly 5 x 8 km., which will establish the scientific basis for CO_2 and CH_4 flux determination at the unprecedented time and space scale. This determination would produce a fundamental change in our scientific understanding of the global carbon cycle as well as produce the kind of flux information that would be needed to support international agreements on greenhouse gas emission reductions. We would be able to view CO_2 weather at the resolution of local weather and individual ecosystems. This opens the door for better understanding the feedbacks between the biosphere and atmosphere as never before.

The instrument would exploit the four spectral regions: The Oxygen A-band for pressure and aerosols, the weak and strong bands of CO_2 near 1.61 and 2.06 microns, and a region near 2.32 microns for CO and CH_4. The O_2 and CO_2 components are very similar to the instruments aboard OCO-2, and so we envision OCO-2 in geostationary orbit with the addition of a fourth channel to measure CO and CH_4, but without an oceanic capability.

The talk will additionally focus on the synergy with Low Earth Orbiting satellites (such as OCO-2 and GOSAT) as a contribution in determining surface fluxes from geo-orbit. These measurements over several years would provide a break through reduction in the uncertainty and attribution for the sources of CO_2, CH_4 and CO within the large geostationary field of regard of the GeoCARB. We will provide results for 3 orbital slots (70°E, 110°E, and 90°W; see Figure 1), and then, we will focus on additional studies from the west slot over the Americas.

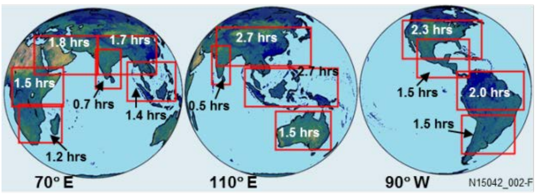

Figure 1. Fields of regard and potential scan blocks and times for scan for three example geostationary slots

Key Words: carbon dioxide, methane, carbon monoxide, geostationary orbit and hosted payload.

Plans and progress on greenhouse gas observations in the Arctic and boreal regions from a highly elliptical orbit (HEO) mission

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Continuous satellite-based atmospheric CO_2 and CH_4 observations are desirable for studies of the carbon cycle. Multiple geostationary (GEO) mission concepts are under consideration by international space agencies, which would greatly improve observational capabilities; however, the high viewing angles from GEO poleward of approximately 55°N/S prohibit coverage of the Arctic and much of the boreal region. The Canadian Space Agency has recently funded new studies to explore the feasibility of a mission optimized for observing northern high latitudes (~50-90°N). Two satellites, each equipped with an imaging Fourier transform spectrometer (IFTS) operating in the near-infrared (NIR) and potentially also the thermal infrared (TIR) in a highly elliptical orbit (HEO) configuration offer the potential for quasi-geostationary CO_2 and CH_4 coverage of the high latitude regions. Such observations are more challenging at high latitudes than at lower latitudes due to large solar zenith angles and reduced albedo over snow in the 1.6 micron band. In spite of these challenges, earlier work demonstrated that HEO observations would yield improved constraints on regional-scale Arctic and boreal CO_2 fluxes, where permafrost and other components of the carbon cycle will be important to monitor over the coming years. Recently-initiated studies and future efforts aim to optimize the observing characteristics (repeat cycle, pixel size, spectral bands, integration time, signal-to-noise ratio, etc.) to quantify northern high latitude carbon cycle signals of scientific interest.

Keywords: Arctic, boreal, CO_2, CH_4, Fourier transform spectrometer, highly elliptical orbit

NASA, Greenhouse Gases, and the Decadal Survey

Ken Jucks
NASA HQ

NASA has many outside "customers" who influence which missions it develops at any point in time. The primary influence comes from the science community either in the form of the National Research Council led Decadal Survey or through peer reviewed proposals such as the Earth Venture series of solicitations. The influence comes from entities that decide NASA's overall budget, the executive and legislative branches of the US government. These four influences do not always sync to provide a clear path to setting a coherent observation program. NASA currently has solid plans to continue OCO-2 operation as long as it is producing quality science data. OCO-3 is currently slated to be deployed on the ISS in 2018 and will operate there for as long as the ISS and operates. Funds to initiate formulation of ASCENDS have not been approved in any NASA budget to date and most likely will not before the release of the next Decadal Survey some time in mid 2017. The next Decadal Survey has listed a number of study panels (Global Hydrological Cycles and Water Resources; Weather and Air Quality: Minutes to Subseasonal; Marine and Terrestrial Ecosystems and Natural Resource Management; Climate Variability and Change; Seasonal to Centennial; Earth Surface and Interior: Dynamics and Hazards), none of which are directly related to Atmospheric Carbon Cycle observations. But Carbon Cycle science is considered a highly likely cross cutting theme among all of these focus areas. Hence it's highly likely that recommendations will come forward that NASA should plan on further space-based Greenhouse Gas observations some time after OCO-2 and OCO-3. I will discuss one interpretation (mine) of how all of these inputs may play out in the coming years.

Keywords: NASA, satellites

Towards an operational observing system to monitor fossil CO_2 emissions

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Carbon dioxide, CO_2, is the most important greenhouse gas in the atmosphere released through human activity and its concentration is increasing causing climate change. The greatest contribution to the increase in atmospheric CO_2 comes from emissions from the combustion of fossil fuels and cement production. Errors associated with their emission estimates may translate into ill-informed policy decisions about future emission reductions.

The capabilities to assess CO_2 emissions in a reliable and consistent manner are severely limited at present. In 2015, upon request of the European Commission, a group of experts outlined a vision and a preliminary roadmap for a European integrated observation system dedicated to the monitoring of fossil CO_2 emissions. The development and operation could be undertaken within the Copernicus programme. The atmospheric measurements would be used in an operational system based on three complementary components consisting of measurements, bottom-up inventories and data-assimilation system.

The satellite and in-situ atmospheric measurements would enable the accurate, transparent and consistent quantitative assessment of CO_2 emissions and their trends at the scale of megacities, regions, countries, and the Earth as a whole. Such a capacity would provide the European Union with a unique and independent source of actionable information, which would support multiple stages of the policy cycle.

This presentation outlines the current and future scientific and technical capabilities that could enable such an observation system, in particular in view of the need to develop information sources adequate to support the goals set by the recent COP21 UN conference.

Keywords: future missions, carbon dioxide, emissions, Copernicus, ESA

GOSAT CO_2 and CH_4 calibration and validation activities with portable FTS measurements

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T. Tanaka (5), L. Iraci (5), C. Bruegge (6), F. Schwandner (6), D. Crisp (6)
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The column-average dry air mole fractions of carbon dioxide (XCO_2) and methane (XCH_4) were measured with a portable Fourier transform spectrometer (FTS), EM27/SUN Near-IR, using direct sunlight at 1) Caltech, in Pasadena, a northern Los Angeles suburb, 2) Chino, a dairy region east of Los Angeles, and 3) Railroad Valley (RRV), a desert playa in Nevada. They were conducted during the GOSAT/OCO-2 joint campaign for vicarious calibration and validation (cal/val) and its preparatory experiments in June-July 2015.
Measurements from the JAXA EM27/SUN were compared with those from the Total Carbon Column Observing Network (TCCON) and from the Caltech EM27/SUN at Pasadena. We observed diurnal enhancements by advection from the Los Angeles basin, a diurnal cycle at Chino dairy area as a CH_4 point source. Finally, we conducted the cal/val campaign at RRV coincident with GOSAT and OCO-2 overpass observations, CO_2 and CH_4 profiling measurements by the Alpha Jet research aircraft as a part of the NASA Ames Alpha Jet Atmospheric eXperiment (AJAX). In 2016, we will plan to perform newly installed EM27/SUN Mid-IR with CO absorption band, which is an additional target of GOSAT-2 mission.

Keywords: GOSAT, carbon dioxide, methane, calibration, validation

Inter-comparison between GOSAT and OCO-2 SWIR-band Spectral Radiance over Railroad Valley

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The Greenhouse gases Observing SATellite (GOSAT) was launched on January 2009 and continues to operate after more than seven years. The Orbiting Carbon Observatory 2 (OCO-2) was launched on July 2014. Both mission were designed to measure atmospheric carbon dioxide concentrations using reflected solar radiance with three SWIR spectral bands (O_2 A band, Weak-CO_2 band and Strong-CO_2 band).
This work describes the inter-comparison of GOSAT and OCO-2 SWIR spectra over spatially and temporally coincident observation points. The inter-comparison of spectral radiance is an essential first step of cross-validation of the different spectrometers.
We first took the temporally coincident and spatially collocated data in Railroad Valley (RRV) in Nevada, USA. GOSAT pointed at RRV from its descending paths 36 and 37 in target mode. OCO-2 also targeted RRV from its ascending paths 136~139. We selected the smaller OCO-2 footprint data within the larger 10.5 km diameter GOSAT footprint. As the surface reflection in RRV is not Lambertian and GOSAT and OCO have different observation geometry, we picked up the data with similar BRDF characteristics. We also use MODIS reflectance data, which is higher spatial resolution than GOSAT and OCO-2, to correct and reconcile their different footprint size.
Our analysis shows that GOSAT and OCO-2 Level 1 products, after radiance conversion and long term degradation correction, agree well within much better than 5%.

Keywords: GOSAT, OCO-2, calibration, SWIR

Optimizing observation geometry using the agile GOSAT pointing mechanism for more precise and accurate X_{CO2} retrieval

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In order to achieve more precise and accurate X_{CO2} retrieval, it is important to investigate the relationship between the X_{CO2} accuracy and the observation conditions such as geometry (sun and satellite positions) and conditions at observation point (albedo, SNR, aerosols, polarization, etc.).

Using the GOSAT Level 2 (ACOS L2S V3.3) products from 2010 to 2013, the relationship between X_{CO2} retrieval accuracies and the observation conditions was investigated statistically. Also, the relationship between the spectral polarization characteristics and aerosol information was investigated by analyzing the GOSAT Level 1B products and aerosol data. The global X_{CO2} retrieval accuracy was calculated as the standard deviations of three-time continuous observation for the same footprints. These results showed that the forward scattering observation generally achieves higher accuracy of X_{CO2} retrieval than the backward scattering observation. In addition, the spectral polarization characteristics have information of the aerosols, which is one of the main systematic errors of the X_{CO2} retrieval. These results suggest the agile GOSAT pointing mechanism realizes the observations for more precise and accurate X_{CO2} retrieval.

Keywords: GOSAT, carbon dioxide, statistical analysis, pointing

Assessing potential applications of collocated OCO2 Oxygen-A band and CALIPSO lidar measurements

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OCO2 O_2-A band measurements are very information rich since the spectral measurements are sensitive to various surface, cloud and aerosol properties.

OCO-2 has been in the A-train orbit for months. A-train satellites, including many active and passive remote sensing observations, provide useful information for the assessment of potential applications of the OCO-2 A-band measurements. CALIPSO is one of the A-train satellites. Its lidar measurements provide accurate cloud/aerosol detection, vertical distribution of aerosol and cloud properties.

This study uses collocated OCO-2 A-band and CALIPSO lidar measurements for retrievals of various physical properties, such as surface and cloud top pressure, cloud optical depths, and microphysical properties.
An initial retrieval of these gas concentrations was performed for measurement of the scans of cloud-free conditions over land. These results showed that column-averaged dry air mole fractions of both CO_2 and CH_4 in the northern hemisphere were higher than those in the southern hemisphere. These latitudinal differences agree with results obtained from ground-based sources and other satellite observations; however, the absolute values of the gas concentrations from GOSAT data seem to have been underestimated.

Keywords: OCO-2, O_2-A band, CALIPSO, lidar, pressure, clouds

TCCON H_2O retrievals for satellite validation

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Atmospheric water vapour is a critical component of the climate and hydrological systems, and the largest contributor to the atmospheric greenhouse effect. Climate change induced by increasing anthropogenic emissions of carbonaceous greenhouse gases is expected to influence the role that water and water vapour plays in the atmosphere, with changing spatial and temporal distributions, and an expected positive feedback effect. Monitoring of atmospheric water vapour amounts is therefore a crucial component of the atmospheric observing system, and satellite measurements, especially those co-located with measurements of other greenhouse gas abundances, are in turn an important contributor to water vapour knowledge. While the primary focus of GOSAT is on measurements of CH_4 and CO_2, measurements of H_2O and its isotopologue, HDO, are also possible.

In this presentation, we compare ground-based retrievals from TCCON, the primary validation network for GOSAT and other satellite-based sensors of column-averaged greenhouse gas mole fractions, to column H_2O from independent balloon-borne sonde measurements and retrievals of H_2O and HDO from the MUSICA network. This provides an extended calibration for the TCCON retrievals. The resulting ground-based retrievals are then compared to GOSAT retrievals of H_2O to validate their spatial and temporal variability and assess any potential biases in the satellite product.

Keywords: GOSAT, TCCON, water vapour, retrieval, validation

Aerosol retrieval algorithm and aerosol properties retrieved from GOSAT/TANSO-CAI

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We have developed a satellite remote sensing algorithm for aerosol retrievals. This algorithm uses the information of multiple wavelengths and pixels at once with spatial constraint of aerosol properties (MWPM). This method is suitable for retrieving aerosol optical properties in the region with heterogeneous ground surface, i.e. the surface reflectance is spatially inhomogeneous, such as an urban area.

We applied this algorithm to GOSAT/TAONSO-CAI that has a characteristic band at wavelength 380nm whose land surface reflectance is low and that is useful to distinguish aerosol from cloud by aerosol absorbing property. We use CAI four bands to retrieve aerosol optical properties. Retrieved parameters are aerosol optical thickness (AOT) of fine and coarse mode, a volume soot fraction in fine mode particles, and surface albedo of each observed wavelength. We simultaneously retrieve all the parameters that characterize pixels in each of sub-domains consisting the target area. Then, single scattering albedo (SSA) and Angstrom exponent are derived.

We compared retrieved and ground-observed AOTs at the closest pixel to AERONET or SKYNET sites, and retrieved AOTs were in agreement with ground-observed ones within ±0.07 in urban area. We retrieved aerosol properties in the case of forest fire in Indonesia in 2015, and also tried to retrieve AOT over land and ocean at once. From the result, derived AOTs of fine mode aerosol are high around smoke region and on the leeward side of the forest fire spot, and also the fine mode AOT is high along the coast of downwind over ocean. It is likely that our algorithm works well over an urban area and in the case of forest fire. We will apply the algorithm to GOSAT-2/TANSO-CAI-2 imager data.

Keywords: GOSAT, aerosol, retrieval

An observational study of urban air pollution with GOSAT/CAI

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Air pollution has become a serious problem in urban areas across East Asia. In Japan, air pollution levels similar to those during the period of high economic growth have been reduced; nevertheless, in recent years, there is increasing concern about air pollution caused by particulate matter (PM) and its effect on human health. Air pollution caused by PM is widely thought to be caused by pollutants that come from overseas. However, the transboundary air pollution that is observed in the high concentration of PM in Japan and the possible polymerization of urban air pollution is thought to increase the concentration of pollutants.

In this study, the concentration of PM in urban areas is analyzed in detail to clarify its state and causes of its change. GOSAT/CAI aerosols were used to investigate the aerosol properties in each city in Japan, considering the differences in aerosol properties depending on the characteristics of each area and the scale of each city. Aerosols optical thickness (AOT) increase from spring to summer in Japan. The value of surface observed PM concentration indicates similar seasonal change. The origins of air pollution were also examined, focusing on the comparison between aerosol properties observed from satellites and the concentration of PM observed on the ground.

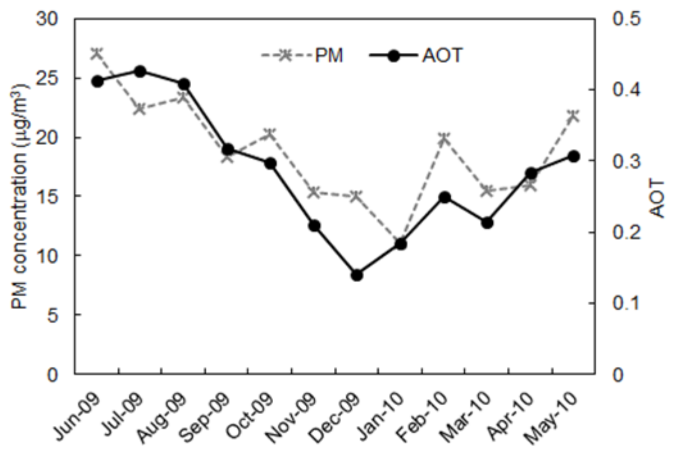

Figure1. Monthly mean PM concentration and GOSAT/CAI AOT average of about 30 cities in Japan.

Keywords: GOSAT, CAI, aerosol, PM

The CO_2 slicing algorithm for the TIR cloud/aerosol products of TANSO-FTS2/GOSAT-2

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[4)]Meteorological Research Institute

Greenhouse gases Observing Satellite (GOSAT) – 2 is scheduled to be launch in 2018. The main sensor, Thermal And Near-infrared Sensor for Observation (TANSO) 2 has 3 bands in near infrared region and 2 bands in thermal infrared region. The CO_2 slicing technique, which is one of cloud detection technique using thermal infrared radiance from space is planned to be applied to data from TANSO-FTS2 for cloud screening and retrieval of their properties. This presentation describes the procedure of CO_2 slicing technique and the analytical results using TANSO-FTS/GOSAT data. The weighting functions which represent sensitivity profiles were calculated at each channel in the range of 700-755 cm^{-1}. The channels were reconstructed as sets of several spectral channels for each height level based on the peak heights of the weighting functions. Subsequently, the channel combinations were optimized based on simulation studies for several temperature profile patterns for each latitude and temperature at 500 hPa height level. This algorithm was applied to GOSAT data and the results were compared with CALIPSO data.

Keywords: TANSO-FTS2, thermal infrared, cloud, dust

Primary verification of new cloud discrimination algorithm Used with GOSAT TANSO-CAI in Borneo Island

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Greenhouse gases Observing SATellite-2 (GOSAT-2) will be launched in fiscal year 2017. GOSAT-2 will be equipped with two Earth-observing instruments: the Thermal And Near-infrared Sensor for carbon Observation Fourier Transform Spectrometer 2 (TANSO-FTS-2) and the Cloud and Aerosol Imager 2 (TANSO-CAI-2). The FTS-2 data will be used to determine atmospheric concentrations of greenhouse gases such as CO_2 (carbon dioxide), CH_4 (methane), and CO (carbon monoxide). CAI-2 is a push-broom imaging sensor that has forward- (+20°) and backward-looking (-20°) bands for observing the optical properties of aerosols and clouds, and for monitoring the status of urban air pollution and transboundary air pollution over oceans. An important role of CAI-2 is to perform cloud discrimination in each direction because the presence of clouds in the instantaneous field of view (IFOV) of the FTS-2 leads to incorrect estimates of the concentrations. Thus, the FTS-2 data suspected to have cloud contamination must be identified by a CAI-2 cloud discrimination algorithm and rejected. For GOSAT-2, a new cloud discrimination algorithm using support vector machines (SVM) was developed. Visual inspections can use the locally optimized thresholds, although the existing GOSAT CAI cloud discrimination algorithm and the new algorithm use the common thresholds globally. Thus, the accuracy of visual inspections is better than that of these algorithms in limited regions without areas such as ice and snow, where it is difficult to distinguish cloud and ground surfaces. In this study we evaluated the accuracy of the new cloud discrimination algorithm by comparing it with the existing CAI cloud discrimination algorithm based on visual inspection of the same CAI images in Borneo Island.
We will present our latest results.

Keywords: GOSAT-2 CAI-2, cloud discrimination, SVM, primary verification

Are the OCO-2 XCO2 observations good enough for science?

C. O'Dell, A. Eldering, C. Frankenberg, D. Crisp, M. Gunson, and P. Wennberg

Observations of atmospheric carbon dioxide from the Orbiting Carbon Observatory-2 (OCO-2) have the potential to be revolutionary in their impact on our understanding of carbon sources and sinks. For this to be achieved, however, requires the observations to have sub-ppm systematic errors; the large data density of OCO-2 generally means that random errors will be of lesser importance in terms of regional scale fluxes. In this presentation we report on results from the Atmospheric Carbon Observations from Space (ACOS) algorithm as applied to the first year of OCO-2 observations, with a particular focus on filtering and bias-correction of the OCO-2 data "Nadir" and "Glint" mode data. In general, we find the random errors to be low (0.5-2.0 ppm), consistent with the high signal-to-noise ratio of the instrument. Comparisons to validation data are used to form a bias-corrected XCO2 product, similar to that for ACOS/GOSAT retrievals. Comparisons to data-constrained inverse models reveal some striking differences, in particular an apparent OCO-2 high bias in the southern hemisphere winter over ocean and a time-varying low bias in the tropical oceans. Biases over land, in particular the tropical deserts, are also apparent. These biases are discussed with an eye toward how to make progress with OCO-2 data on the big questions in carbon cycle science.

Accounting for systematic differences between OCO-2 retrievals and model values of XCO_2 in an assimilation system

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(2) Universities Space Research Association (USRA)

(3) Science Systems and Applications, Inc. (SSAI)

The quality of any assimilation system depends upon the accuracy of its statistical models for the systematic and random components of the differences between observations and model values. In particular, systematic differences that are unaccounted for can drive flux inversion systems toward unrealistic conclusions. Retrievals of column-averaged carbon dioxide (XCO_2) from the Orbiting Carbon Observatory 2 (OCO-2) currently have complex and non-negligible systematic differences with model values. The sources of these differences remain unclear and could be the result of both retrieval and model errors.

This presentation summarizes work to separate the retrieval and model error components of systematic data-model differences. First, we assimilate in situ and ground-based total column measurements to compute 3-dimensional (3D) fields of CO_2 mole fractions that serve as a rough proxy for the true fields. The resulting analysis 3D fields can be compared directly to OCO-2 retrievals using the retrieval a priori and averaging kernel. Systematic differences in this comparison indicate possible retrieval errors. On the other hand, systematic differences between the analysis 3D fields and a free-running model with no assimilation indicate model biases, which are most likely due to errors in the surface flux fields. Second, we assimilate OCO-2 XCO_2 to compute analysis 3D fields of CO_2 mole fractions based solely on the OCO-2 retrievals. Comparing this analysis with the ground-based analysis results in a time-varying global map of the consistency of the satellite retrievals with the ground-based network. This analysis is thus able to assess the errors of all soundings, not just those in target mode.

Keywords: OCO-2, carbon dioxide, data assimilation, systematic errors

Using a surrogate model to estimate patterns of bias in retrieved X_{CO2} for OCO-2 observations

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A highly precise and unbiased estimate of the mean dry-air column mixing ratio of carbon dioxide, X_{CO2}, is essential to determining regional surface fluxes. Patterns of bias in retrieved X_{CO2} from OCO-2 is examined using a computationally-efficient surrogate model that is designed to represent key aspects of the OCO-2 retrieval algorithm. A surrogate model facilitates Monte Carlo methods, taking repeated draws from the representative marginal distributions of geophysical parameters in selected regions, synthesizing corresponding radiances, and retrieving the posterior distributions of quantities of interest: X_{CO2} and the posterior error covariance. Sets of such distributions, or templates, for a variety of regions have been developed to match the broad range of measurement conditions encountered by OCO-2. The approach and the patterns in bias of retrieved X_{CO2} and the posterior error covariance will be presented, along with a comparison to similar estimates from TCCON/OCO-2 measurements.

Keywords: OCO-2 bias estimates surrogate model

Retrieving CO_2 from the NASA OCO-2 observations using RemoTeC

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The Orbiting Carbon Observatory-2 (OCO-2) was launched on 02 July 2014 to monitor the global distributions of carbon dioxide (CO_2) from space. The instrument is designed to provide the required sensitivity, resolution and coverage needed for quantifying CO_2 sources and sinks on regional scales.

Here, we aim to exploit the OCO-2 specific characteristics and observation modes for further improvement of our CO_2 retrievals. Therefore, the RemoTeC algorithm, previously applied to CO_2 and CH_4 retrievals from GOSAT, will be expanded to be used in the multi-angle target mode of OCO-2. This can help to reduce retrieval uncertainties emerging from atmospheric scattering of aerosol and cirrus. As a first step, we adapt the algorithm to include polarization within the atmosphere for single-angle viewing observations to account for the polarization sensitivity of the OCO-2 instrument. Here, we describe the algorithm and show applications to OCO-2 measurements and the validation with on-ground TCCON measurements. This algorithm is an extension of the existing RemoTeC algorithm developed by SRON and KIT.

Keywords: CO_2 retrieval, OCO-2, target mode

Using OCO-2 Data to Analyze Anthropogenic CO_2 Hotspots: First Preliminary Results

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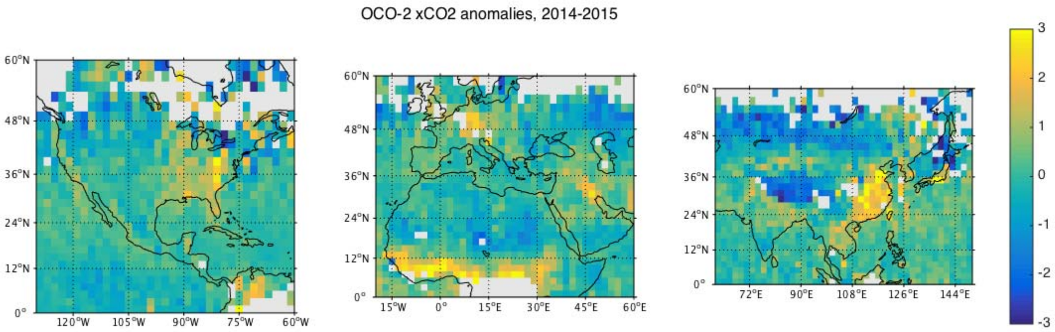
NASA's Orbiting Carbon Observatory 2 (OCO-2) was launched on 2 July 2014 to monitor global atmospheric concentration and flux of CO_2 from space. As of March 2016, the instrument has collected more than one year of data. In this paper, we utilize this data record to analyze hotspots of anthropogenic CO_2 sources. Our aim is to utilize advanced techniques developed to analyze spaceborne nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) both short-lived atmospheric trace gases with both anthropogenic and natural sources datasets. Unfortunately, trends, seasonality, long lifetime, and large atmospheric background significantly complicate the analysis of CO_2 hotspots. Our methodology is based on simultaneously deseasonalizing and detrending the data, and then mapping the remaining the so-called anomaly data to a grid.



In this paper, we show that the main anthropogenic pollution regions like eastern USA, Central Europe, East Asia, and Middle East are easily detectable from our OCO-2 CO_2 anomaly maps. In addition, also smaller sources are visible. In order to better understand CO_2 anomaly maps, we simultaneously analyze the established NO_2 and SO_2 maps observed by Dutch-Finnish Ozone Monitoring Instrument (OMI) onboard NASA's Aura spacecraft and use these data records also to qualitatively validate our results. In future, as the OCO-2 data record gets longer, we hope to individually detect all the Megacities.

Keywords: OCO-2, carbon dioxide, anthropogenic emissions, hotspots, validation, OMI, nitrogen dioxide

Investigating Regional Carbon Flux Estimates from the GEOS-Carb system using OCO-2 total column CO_2 observations

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The GEOS-Carb modeling system at NASA's Global Modeling and Assimilation Office leverages the GEOS family of models to deliver a consistent set of land and ocean flux estimates. Recently as part of this system, we have developed a top-down flux estimation capability that is designed to ingest high-density atmospheric CO_2 observations and estimate fluxes at high spatiotemporal resolutions (spatial: ~1° and temporal: daily). With the data available from the Orbiting Carbon Observatory-2 (OCO-2) mission, the assimilation system is being used to examine the degree to which the OCO-2 total column observations (X_{CO2}): (a) are constraining surface fluxes with reasonable precision and accuracy, and (b) providing additional information relative to the high precision but sparse in situ observational network.

We will present global and regional flux estimates based on observations from OCO-2 and NOAA's surface flask network. Evaluation of the flux estimates and posterior CO_2 concentrations will focus on two regions: (a) North America, and (b) South America. The North American case enables us to compare flux estimates using OCO-2 observations relative to the constraints provided by the current surface flask network, and show a weaker than usual summertime drawdown in 2015. On the other hand, the South American case focuses on a traditionally data sparse region, and demonstrate that the high-density sampling of OCO-2 picks up signatures of increased carbon sources, likely due to the impact of El Nino teleconnections. As the OCO-2 data matures, we will refine these test regions and explore additional cases where we observe anomalies in the X_{CO2} distribution, for example, the Tropical and the Southern Ocean sectors. Such anomalies indicate the possibility of previously unobserved fluxes, transport variability, and/or impact of the current El Nino conditions on land- /ocean-atmosphere carbon exchanges.

Keywords: OCO-2, CO_2 flux estimation, GEOS-5, X_{CO2} anomaly detection

CO_2 Retrieval over East Asia using CAI aerosol information

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Large portion of column abundance CO_2 (XCO_2) retrievals using the GOSAT measurements data are typically screened out during the quality control process, otherwise retrieval errors tend to increase, in East Asia, where aerosol concentrations are consistently high throughout the year. Various strategy for handling aerosol information was attempted with the aim of reducing those retrieval errors of XCO_2 induced by aerosol information. In this study, the XCO_2 was retrieved from GOSAT TANSO-FTS measurements using aerosol retrievals from TANSO-CAI measurements. CAI aerosol algorithm provides aerosol type and AOD information simultaneously for the same geometry and optical path along the FTS. In order to employ more reliable a priori information of CO_2 over East Asia, Carbon Tracker-Asia data was used. The developed Yonsei university CArbon Retrieval (YCAR) algorithm is based on optimal estimation method and VLIDORT V2.6 was used to calculate the radiances and weighting functions. The retrieval results were evaluated by comparing with ground-based TCCON measurement and operational GOSAT XCO_2 retrieval (NIES, ACOS, and University of Leicester). The retrieved results show reliable annual cycle, but with negative bias by 2.04 ppm, which is comparable with operational algorithms. The regression line is close to one to one with the RMSE of 2.03. Even after the post screening, the developed YCAR algorithms provided increased number of XCO_2 retrieval compared to the operational product by 35 – 90%, which could be substantial advantage over East Asia. The error analysis of result shows retrieval error by 1.1ppm. The spatial-temporal sampling difference between GOSAT XCO_2 and TCCON measurements is averagely 0.324 - 0.358 ppm which could not be overcome with algorithm.

Keywords: GOSAT, carbon dioxide, East Asia

Applying GOSAT and other satellite retrievals to understand spatiotemporal variabilities and emissions of GHG's over East Asia

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Here we introduce use of satellite retrievals to understand the spatiotemporal variabilities and emissions of GHGs over East Asia. Firs, we demonstrated a sharp contrast to the seasonal and latitudinal gradient of atmospheric CO_2 over East Asia, where there are relatively few ground-based observations. The Greenhouse gases Observing SATellite (GOSAT) column-averaged dry air CO_2 mole fraction (xCO_2) retrieved by NASA's Atmospheric CO_2 Observations from Space (ACOS) (2009-2011) program and GEOS-Chem nested-grid CO_2 results are used. The strong anthropogenic emissions mainly from China and intensive vegetation uptake from northeastern Asia lead to a clear seasonal change of the xCO_2 between spring maximum and summer minimum (~15 ppm).

In addition, we introduce our efforts to constrain the emissions of CO_2 from GOSAT data using 4-Dvar inverse modeling framework and we show some case study for the application. This study represents the current progress to understand sub-continental scale atmospheric CO_2 variabilities and its emissions with recent satellite retrievals and nested-grid modeling.

Keywords: Satellite retrievals, CO_2, spatiotemporal variabilities, emissions

A Study of Extraction and Analysis of Emission and Absorption Events of Greenhouse Gases with GOSAT

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Atmospheric concentrations of carbon dioxide (CO_2) and methane (CH_4) have been increasing since mid-18th century, and now global warming by anthropogenic greenhouse gases becomes a challenging problem. Global observation with high spatial-temporal resolution and accurate estimation of sources and sinks are important to understand greenhouse gases dynamics. Greenhouse Gases Observing Satellite (GOSAT) was launched in January 2009, and XCO_2 and XCH_4, which represent column-averaged dry-air mole fractions of CO_2 and CH_4, are observed globally with high spatial resolution.

In this study, two datasets are used as GOSAT observation data. One is ACOS GOSAT/TANSO-FTS Level 2 Full Product B3.5 by NASA/JPL, and the other is NIES TANSO-FTS L2 column amount (SWIR) V02.xx. They are different to the extent of retrieval algorithms. We expected to find the common observation results as well as the different features as statistical bias and deviation in spatial and temporal variations. In addition, CarbonTracker developed by NOAA/ESRL are also analyzed for comparing between GOSAT observation data and atmospheric model data.

To detect emission and absorption events by using GOSAT observation data, time series data of XCO_2 and XCH_4 are obtained globally from the GOSAT observation and atmospheric model datasets, and functions which expresses typical inter-annual and seasonal variation are fitted to each spatial grid. Anomalous events of XCO_2 and XCH_4 are extracted by the difference between GOSAT observation data and the fitted function. The difference between GOSAT observation and atmospheric model represents unconsidered events by atmospheric model. To discuss the mechanism of the extracted events, further analyses are also performed to the extracted events.

Keywords: GOSAT, carbon dioxide, methane, anomaly, bias assessment

Towards assessing CO_2 emissions from fossil fuel combustion by GOSAT observations of localized CO_2 enhancements

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Growth of atmospheric CO_2 abundance is primarily caused by emissions from fossil fuel combustion, major part of which happens in large power plants and megacities. A satellite-based capability of observing CO_2 enhancement due to man-made emissions remotely should help detecting potential biases in reported emission inventories. We employed an atmospheric transport model to attribute column-averaged CO_2 mixing ratios (X_{CO2}) observed by Greenhouse gases Observing SATellite (GOSAT) to emissions from large point sources such as megacities and power plants. X_{CO2} enhancements estimated from observations were compared to model simulations implemented at the spatial resolution of the satellite observation footprint (0.1°×0.1°). We found that the simulated X_{CO2} enhancements agree with the observed over several continental regions across the globe, for example, for North America with an observation to simulation ratio of 1.05±0.38 ($p<0.1$), but with a larger ratio over East Asia (1.22±0.32; $p<0.05$). The obtained observation-model discrepancy (22%) for East Asia is comparable to the uncertainties in Chinese emission inventories (~15%) suggested by recent reports. Our results suggest that by increasing the number of observations around emission sources, satellite instruments like GOSAT can provide a tool for detecting biases in reported emission inventories.

Total Column Water Vapor from OCO-2

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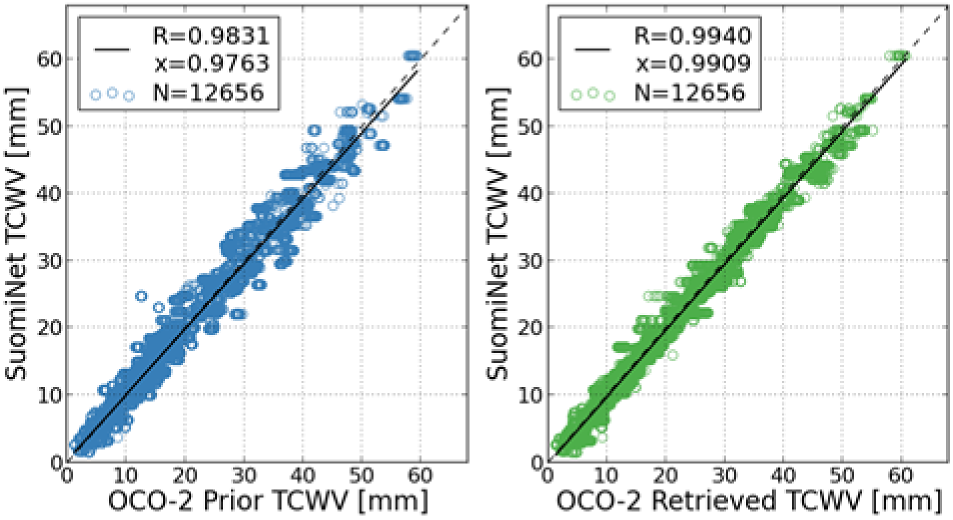
Measurements of atmospheric water vapor provide useful information for a wide range of applications including hydrological cycle studies, radiation budget studies, weather forecasting, and climate change studies. While many existing ground-based networks provide highly precise and accurate measurements of water vapor, the large temporal and spatial variability of water vapor results in the need for additional information on a global scale. Currently, global spaced-based information on water vapor comes from a number of satellite instruments in the microwave (SSM/I, AMSR-E/2, TMI), thermal infrared (AIRS, IASI, CrIS, HIRS), and visible (MODIS, MERIS). However, all of these have limitations in terms of both accuracy and spatial coverage.

In this work we investigate the accuracy of Orbiting Carbon Observatory-2 (OCO-2) total column water vapor measurements by comparing them to independent observations, including those from SuomiNet, which is a ground-based Global Positioning System (GPS) network. Though OCO-2's primary mission is to measure the total column of atmospheric carbon dioxide (X_{CO2}), it also measures total column water vapor with the NASA Atmospheric CO_2 Observations from Space (ACOS) X_{CO2} retrieval algorithm using information contained in two near-infrared absorption bands at 1.6 and 2.0 μm. The information in these bands primarily concerns CO_2, but several water vapor lines in each band enable the retrieval of water vapor simultaneously with X_{CO2}. We assess the overall ability of OCO-2 to measure total column water vapor, and examine patterns and biases in both time and space. Initial results are promising, as they show an improvement relative to ECMWF Integrated Forecasting System total column water vapor estimates.



ECMWF IFS (used as the OCO-2 prior; left panel) and OCO-2 retrieved (right panel) TCWV vs. SuomiNet TCWV co-located to within 0.1° and 30 min.

Keywords: OCO-2, total column water vapor, TCWV, ACOS, GPS, SuomiNet, ECMWF

Simultaneous observations of solar-induced chlorophyll fluorescence and atmospheric CO_2 dynamics by GOSAT

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In these decades, global warming has progressed owing to increase of greenhouse gases (GHGs) such as CO_2. To deal effectively with this problem by mitigation and adaptation, it is necessary to monitor emission and sequestration of GHGs with their underlying mechanisms including biogeochemical processes and human activities. Terrestrial ecosystem, which is the large carbon sink, absorbs 123 Pg carbon per year through plant photosynthesis (IPCC 2014). Satellite remote sensing has been used to monitor the spatial and temporal dynamics of terrestrial ecosystems that are responsible for photosynthetic CO_2 absorption. Such observation provides us with geographical information on the potential distribution of carbon sequestration by the aid of ecosystem models. However, as the photosynthesis of a given vegetation is quite sensitive to meteorological changes such as radiation, temperature and precipitation, we need to observe the photosynthetic 'activity' in a physiological sense, together with the atmospheric CO_2 concentration over continental and global scales. Joiner et al. (2011) and Frankenberg et al. (2011) have suggested that TANSO FTS on Greenhouse Gases Observing Satellite (GOSAT) could detect overlapping spectral of solar-induced chlorophyll fluorescence (SIF) emitted by terrestrial vegetation and Fraunhofer line. The chlorophyll fluorescence is photons of red and far-red light that emitted by chlorophylls, and in plant ecophysiology it has been a biophysical index to examine the photosynthetic responses to environmental stresses such as extreme temperatures and drought. Thus SIF remote sensing is drawn considerable attention as a new technique to observe the photosynthetic activity of the vegetation. In this paper we will present our on-going and future challenges by GOSAT and GOSAT-2 to observe the photosynthetic activity of terrestrial ecosystems and its possible consequences with the atmospheric CO_2 concentration from national, continental to global scales under climate change.

Keywords: GOSAT, carbon cycle of terrestrial ecosystem, SIF

Global Atmospheric Inversions of CO_2 and Solar-Induced Fluorescence (SIF)

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The OCO-2 satellite was launched on July 2, 2014, to monitor global atmospheric concentration and flux of CO_2 from space. We present a novel new atmospheric inversion scheme that solves for respiration and gross primary production (GPP) using a decomposition of multiplicative biases into seasonal harmonics. Initial CO_2 flux results for the time period of September 2014 to December 2015 will be presented with a focus on temporal corrections to the flux. We plan to use SIF to provide independent constraint upon GPP allowing flux results to be interpreted mechanistically to independent estimates such as eddy covariance data and inventory based data such as harvest yields. We will present the structure for incorporating SIF into the inversion as well as any preliminary results from the coupled SIF/CO_2 inversions.

Keywords: carbon dioxide, inversions, fluorescence

Ground-based Network of Long-term Measurement of Sun-Induced Chlorophyll Fluorescence

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(6) National Institute for Environmental Studies (NIES)

Terrestrial ecosystems, forest, grassland and so on, absorbs atmospheric CO_2 as a greenhouse gas by photosynthesis, and are thought to mitigate global warming. Estimation of geographical extent of their photosynthesical activity is very crucial for the understanding of global climate change in future. However, conventional vegetation indices (for ex, NDVI, EVI, etc.) representing the greenness of ecosystem, reduce the accuracy for photosynthesis estimation in the particular situations; .e.g., the overestimation in evergreen forest in winter and in drought.

Chlorophyll fluorescence is emitted from chloroplast to release the overflown energy of incident sunlight (so-called as Sun-Induced Fluorescence; SIF). Recently, Several studies proved that SIF could be utilized for photosynthesis estimation at the ecosystem spatial scale (Zarco-Tejada et al., 2013, AFM, etc.) as shown by the strong correlationship between SIF and gross primary production (GPP). On the other hand, the availability of SIF is reduced due to small number of ground-based measurement thought highly evaluated potential of them.

This study compiles the SIF derived at five different ecosystems at tower-based flux stations in Japan (all belongs to both Phenological Eyes Network (PEN) and AsiaFlux): paddy field in Mase, grassland in Tsukuba university, deciduous broad-leaf and evergreen coniferous forests in Takayama, deciduous coniferous forest in Fujihokuroku. The SIF is calculated in the O_2-A band around the wavelength of 760 nm by area-ratio Fraunhofer line depth (aFLD) method. We will compare the SIF to eddy GPP flux on the flux tower based ground measurement during 2005-2013 and show the features on the availability of the SIF for the estimation of ecosystem photosynthesis.

Calibrations as well as validation should be conducted to improve the quality of GOSAT retrievals.

Keywords: GOSAT, carbon dioxide, methane, retrieval, validation

An improved Aerosol Scheme for the GHG Retrieval from GOSAT

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More than 5 years of global observations of the atmospheric distribution of CO_2 and CH_4 are now available from GOSAT. These datasets, once combined with models of atmospheric transport, provide a unique resource for constraining regional CO_2 and CH_4 surface fluxes. However, already small regional biases (<1%) in the data acquired from space can lead to unreliable flux estimates. Besides, uncertainties in spectroscopy and instrument calibration, limitations in the scene-specific description of atmospheric aerosols are a main factor for such potential biases.

We have developed a new concept for better constraining the aerosol information used for the CO_2 and CH_4 full-physics retrieval from GOSAT based on the ECMWF MACC (now CAMS) aerosol model which itself is constraint with MODIS AOD. Specifically, we adjust, for each GOSAT retrieval, the a priori setup for AOD, vertical distribution and the two (small and large) aerosol mixtures used in the retrieval with the help of the aerosol mass mixing ratio profiles of the 11 modelled species/size bins.

In this presentation, we will provide an overview over the University of Leicester (UoL) retrieval scheme and we will discuss our new aerosol scheme and its impact on the retrieval of CO_2 which are specifically noticeable over Northern Africa (Sahara desert). We will also present results obtained from GOSAT using our new retrieval setup including validation and model comparisons.

Keywords: GOSAT, carbon dioxide, methane, retrieval, validation

Latest results from the GreenHouse gas Observations of the Stratosphere and Troposphere (GHOST) airborne shortwave infrared spectrometer

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GHOST is a novel, compact shortwave infrared grating spectrometer, designed for remote sensing of tropospheric columns of greenhouse gases (GHGs) from an airborne platform. This is achieved by observing solar radiation at high spectral resolution which has been reflected by the surface. The GHOST system has been specifically designed and built to address the following science objectives: 1) testing of atmospheric transport models; 2) validation of GHG column observations over oceans obtained using polar orbiting satellites; and 3) complement in-situ tropopause transition layer observations from other instruments.

Here we present the latest progress towards retrievals of carbon dioxide and methane from GHOST radiance spectra, which were measured during two distinct flight campaigns. In March 2015 GHOST took part in two science flights on board the NASA Global Hawk unmanned aerial vehicle based at the Armstrong Flight Research Centre in Edwards, California, which comprised long approximately north-south transects over the eastern Pacific Ocean. These flights provided opportunities to observe spatial trends in GHG column concentrations over a regional scale, as well as allowing inter-comparisons with observations from both OCO-2 and GOSAT, which both passed directly over the Global Hawk during the 10th March 2015 flight.

In April and May 2015, GHOST was redeployed on board the Natural Environment Research Council (NERC) Airborne Research and Survey Facility (ARSF), a Dornier-228 twin turboprop aircraft based in the UK which is ideal for slow low-altitude flying. During two science flights over the UK we targeted GHG plumes downwind of various emission hotspots including a coal-fired power plant, an urban centre, and some controlled biomass fires. The two 2015 flight campaigns demonstrate the versatility of the GHOST instrument concept through its application to different GHG measurement regimes using two very different airborne platforms.

Keywords: GHOST, carbon dioxide, methane, retrieval, airborne measurements

Four Years of CARVE-FTS Observations of CO_2, CH_4, and CO in the Alaskan Arctic – Comparison with Satellite Measurements

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The CARVE Science Team

The end of 2015 marked the conclusion of the Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE), a four-year aircraft-based Earth Venture 1 mission to study the carbon balance of the Alaskan Arctic ecosystem, with particular focus on carbon release from melting permafrost. Operating from its base in Fairbanks, AK, the CARVE aircraft covered a range of principle flight paths in the Alaskan interior, the Yukon River valley, and the northern Alaska coast around Barrow and Dead Horse. Flight paths were chosen to maximize ecosystem variability and cover burn-recovery/regrowth sequences. CARVE observations cover the Arctic Spring/Summer/Fall seasons, with multiple flights per season and principle flight path. Science operations started in 05/2012 and concluded in 11/2015.

The CARVE suite of instruments includes flask measurements, in situ gas analyzers for CO_2, CH_4 and CO observations, and a three-band polarizing Fourier Transform Spectrometer (FTS) for column measurements of CO_2, CH_4, CO, their interfering species (e.g., H_2O), and O_2. The FTS covers the spectral regions of 4,200-4,900 cm^{-1} (CH_4, CO), 5,800-6,400 cm^{-1} (CO_2), and 12,900-13,200 cm^{-1} (O_2), with a spectral resolution of 0.2 cm^{-1}. Aircraft-based FTS science observations in Alaska have been performed since 23-05-2012. First-version data products from all CARVE instruments derived from observations during the 2012 campaign were publicly released earlier in 2013.

The FTS has performed well during flight conditions. A recent overhaul of the retrieval algorithm has led to improvements in FTS data quality. We present results from FTS column observations of CO_2, CH_4, and CO, obtained over the entire CARVE observation record from 2012 to 2015, including comparisons of CARVE FTS measurements with satellite observations of GOSAT CO_2 and CH_4 retrieved by NIES, GOSAT CO_2 from JPL/ACOS, MOPITT CO, and CO_2 from OCO-2. The comparison emphasizes coincident CARVE/OCO-2 observations over Alaska during the 2015 CARVE flights.

Keywords: CARVE, GOSAT, OCO-2, Arctic, Boreal Forest, Methane, Carbon Dioxide

Atmospheric CO_2 Variations Observed during Recent ASCENDS Airborne Flight Campaigns

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Accurate observations of atmospheric CO_2 from space can significantly improve our knowledge of global CO_2 distribution and variability. In preparation for future space-based atmospheric CO_2 missions, the NASA Langley Research Center and the Harris Corp. have been collaborating in the development and evaluation of the Intensity-Modulated Continuous-Wave (IM-CW) lidar approach for measuring atmospheric CO_2 from space. Airborne IM-CW lidar systems operating in the 1.57-μm CO_2 absorption band have been developed. With the support from NASA Headquarters and the NASA Langley Research Center, multiple airborne flight campaigns equipped with two IM-CW lidars, in-situ CO_2 sensors, and meteorological state measurement systems have been conducted. Precise atmospheric CO_2 measurements have been obtained by those airborne instruments during these flight campaigns.

Significant atmospheric CO_2 vertical, horizontal and temporal variations on various spatiotemporal scales were observed during these flight campaigns. For example, around 10-ppm CO_2 changes were found within the free troposphere in a region of about 200×300 km^2 over Iowa during a summer 2014 flight. Even over extended forests, about 2-ppm CO_2 column variability was measured within about 500-km distance. For winter times, especially over snow covered ground, relatively less horizontal CO_2 variability was observed, likely owing to minimal interactions between the atmosphere and land surface. Inter-annual variations of CO_2 drawdown over cornfields in the Mid-West were found to be larger than 5 ppm due to slight differences in the corn growing phase and meteorological conditions even in the same time period of a year. Furthermore, considerable differences in atmospheric CO_2 profiles were found during winter and summer campaigns. In the winter CO_2 was found to decrease from about 400 ppm in the atmospheric boundary layer (ABL) to about 392 ppm above 10 km, while in the summer CO_2 increased from 386 ppm in the ABL to about 396 ppm in free troposphere.

Keywords: active remote sensing, in situ measurements, carbon dioxide, ASCENDS airborne flight campaign

Airborne measurements of atmospheric methane using pulsed laser transmitters

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Atmospheric methane (CH_4) is the second most important anthropogenic greenhouse gas with approximately 25 times the radiative forcing of carbon dioxide (CO_2) per molecule. At NASA Goddard Space Flight Center (GSFC) we have been developing a laser-based technology needed to remotely measure CH_4 from orbit. We report on our development effort for the methane lidar, especially on our laser transmitters and recent airborne demonstration.

Our lidar transmitter is based on an optical parametric process to generate near infrared laser radiation at 1651 nm, coincident with a CH_4 absorption. In an airborne flight campaign in the fall of 2015, we tested two kinds of laser transmitters --- an optical parametric amplifier (OPA) and an optical parametric oscillator (OPO). The output wavelength of the lasers was rapidly tuned over the CH_4 absorption by tuning the seed laser to sample the CH_4 absorption line at several wavelengths. This approach uses the same Integrated Path Differential Absorption (IPDA) technique we have used for our CO_2 lidar for ASCENDS. The two laser transmitters were successfully operated in the NASA's DC-8 aircraft, measuring methane from 3 to 13 km with high precision.
We will show data from the airborne demonstration and also discuss the current transmitter approaches for a future space mission.

Keywords: Methane, airborne, experiment, retrieval

Validation of GOSAT Products in the Southern Hemisphere:

Alice Springs Desert Site Study

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This work is part of an ongoing GOSAT RA (research announcement) project on GOSAT validation activities in the southern hemisphere. To address the lack of ground based data in areas with GOSAT M-gain retrievals and to establish benchmark measurements for a proposed TCCON station in the Australian desert environment, we plan to deploy a portable spectrometer (EM-27) to Alice Springs. This work shows preliminary studies on the proposed site. We also show a characterization of the portable EM-27 instrument and an analysis of the GOSAT measurements within the Alice Springs' desert environment.

Keywords: GOSAT, TCCON, carbon dioxide, methane, Southern Hemisphere , validation

Towards TCCON in the Philippines: The importance of monitoring atmospheric carbon in tropical Southeast Asia

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TCCON is dedicated to the precise measurements of greenhouse gases such as CO_2 and CH_4. TCCON measurements have been and are currently used extensively and globally for satellite validation, for comparison with atmospheric chemistry models and to study atmosphere-biosphere exchanges of carbon. With the global effort to cap greenhouse gas emissions, TCCON has taken on a vital role in validating satellite-based greenhouse gas data from past, current and future missions like Japanese GOSAT and GOSAT-2, NASA's OCO-2 and OCO-3, Chinese TanSat, and others. The lack of reliable validation data for the satellite-based greenhouse gas observing missions in the tropical regions is a common limitation in global carbon-cycle modeling studies that have a tropical component. The international CO_2 modeling community has specified a requirement for "expansion of the CO_2 observation network within the tropics" to reduce uncertainties in regional estimates of CO_2 sources and sinks using atmospheric transport models. A TCCON site in the western tropical Pacific is a logical next step in obtaining additional knowledge that would greatly contribute to the understanding of the Earth's atmosphere and better constraining a major tropical region experiencing tremendous economic and population growth. Here, we present an assessment for a possible site in the Philippines where a new TCCON FTS will be installed. We also describe the newly constructed TCCON instrument intended for deployment to the Philippines and show a characterization of its performance and initial measurements at the NIES compound in Japan.

Keywords: TCCON, carbon dioxide, methane, validation

TCCON and AirCore measurements of greenhouse gases over Sodankylä: comparisons with satellite borne observations

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The FTS instrument in Sodankylä participates in the Total Carbon Column Observing Network (TCCON) and in validation of satellite borne instruments. Here we present our observations of dry-air column-averaged carbon dioxide mixing ratio (XCO_2) and methane mixing ratio (XCH_4). The period of observations is from early 2009 until late 2015. The TCCON retrieval version used here is GGG2014. Our ground based FTS instrument is located in Northern Finland at 67.4° N, 26.6° E. We also provide comparisons with the Greenhouse gases Observing SATellite (GOSAT) observations. In average we find good agreement with space borne measurements. For the seven year time period relative difference between the two instruments (space borne–ground based/ ground based instrument) has been -0.04 +/- 0.02 % in case of the XCO_2 retrievals and in case of XCH_4 the relative difference has been -0.09 +/- 0.03 %.

In addition to the remote sensing observations of the greenhouse gases we have started in situ AirCore measurements at Sodankylä to provide comparisons with the FTS retrievals. AirCore is a sampling system, which is known for the accuracy of 0.05% for CO_2 and CH_4 observations and 5% for the CO. The measurements are directly related to the World Meteorological Organization in situ trace gas measurement scales. We have flown AirCore on meteorological balloons, thus we have been able to sample both stratosphere and troposphere. Near the surface in situ tower measurements have been available in Sodankylä. The tower is located in the vicinity of the TCCON instrument.

Keywords: TCCON, GOSAT, AirCore, carbon dioxide, methane, retrieval, validation

Intercomparison between GOSAT and ground-based FTIR data on CO_2 and CH_4 atmospheric concentrations over Western Siberia during 2011-2015

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Siberia is widely affected by forest fires during summer period, which may have an impact on the atmospheric concentration of the carbon gases. This preliminary research presents the results of intercomparison between CO_2 and CH_4 mole fractions in the atmosphere retrieved from a high-resolution ground-based FTIR measurements (recorded at the Kourovka site) and GOSAT L2 data over Western Siberia during summertime 2011-2015. The problem of evaluation of the forest fires contribution into CO_2 atmospheric concentrations is discussed.

This research is supported by grant of RFBR №16-51-50064.

Keywords: GOSAT, FTIR, Siberia, carbon dioxide, methane, retrieval

Simultaneous Nadir Overpass (SNO) Matchups

GOSAT/TANSO-FTS and AQUA/AIRS:

TIR Band April 2009 – December 2015

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The Greenhouse Gases Observing Satellite (GOSAT) was launched in January 2009, to monitor global atmospheric concentration and flux of CO_2 and CH_4 from space. The TANSO-FTS sensor is an interferometer spectrometer measuring shortwave reflected solar radiation with high spectral resolution in three spectral bands. A bore-sighted band 4 uses the same interferometer to measure thermal infrared radiation (TIR) at the top of the atmosphere. This paper is a comparison of the TANSO-FTS TIR band with coincident measurements of the NASA Atmospheric InfraRed Sounder (AIRS) grating spectrometer. The time and space coincident matchups are at the Simultaneous Nadir Overpass (SNO) locations of the orbits of GOSAT and the NASA AQUA satellite. GOSAT/AQUA SNOs occur at about 40N and 40S latitude. A continuous set of SNO matchups has been found from the start of valid radiance data collection in April 2009 through the end of 2015. UW-SSEC has obtained the time, latitude, and longitude of the SNO location using the ORBNAV software at http://sips.ssec.wisc.edu/orbnav. UW-SSEC obtained the matching AIRS v5 L1B radiances from the NASA archive. JAXA has reprocessed the entire TANSO-FTS TIR band using the previous v161.161 and a new calibration version which includes parameter optimizations. The TANSO-FTS has been reduced to the AIRS spectral channels using the AIRS spectral response functions (SRFs). This paper will show the time series of observed brightness temperatures from AIRS and GOSAT TANSO-FTS TIR observations from the SNO matchups. This paper validates the improvements in the GOSAT ground calibration software by providing an independent reference to the AIRS on-orbit calibration accuracy. Improvements in the ground calibration software are expected to lead to improvements in the TIR band Level2 retrievals of CO_2 profiles.

Keywords: GOSAT, carbon dioxide, methane, calibration, bias tuning, retrieval, validation

Measurements of atmospheric CH_4 and CO_2 column averaged concentrations in Sichuan Basin, China using a desktop optical spectrum analyzer

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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. In the area of Sichuan Basin in China, high concentrations of CH_4 column concentrations during the wet seasons have been retrieved by satellite observations and the strong connection between the atmospheric CH_4 concentration and the CH_4 emissions from rice cultivation has been suggested [1,2].

We have measured atmospheric CH_4 and CO_2 column averaged concentrations in Sichuan Basin using a desktop optical spectrum analyzer (OSA: Yokogawa Electric, AQ6370B custom) and a portable sun tracker [3]. Solar absorption spectra in the regions of 1673–1679 and 1569–1575 nm were measured for the CH_4 and CO_2 rotational lines, respectively, from September to November in 2013. The obtained column average values of CH_4 and CO_2 are compared with the results of GOSAT observations. This research was partly conducted under the framework of the GOSAT RA, and supported by a GRENE-ei and a JST programs of the Ministry of Education, Culture, Sports, Science, and Technology, Japan.

[1] S. Hayashida *et al., Remote Sensing of Environment,* 2013, 139, 246–256.
[2] X-C. Qin *et al., Advances in Meteorology,* 2015, DOI: 10.1155/2015/125059.
[3] M. Kawasaki *et al., Atmos. Meas. Tech.*, 2012, 5, 2593–2600.

Keywords: ground-base measurement, column density, instrument, GOSAT, paddy field emission

Temporal characteristics of atmospheric CO_2 over fire affected regions based on GOSAT data

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The atmospheric carbon dioxide (CO_2) concentration exhibits strong seasonal and interannual variation, which strongly impact the interpretation of the sources and sink of CO_2 over certain areas. In fire affected regions, the CO_2 emissions released from vegetation burning significantly affected the temporal variations of atmospheric CO_2 concentrations. Based on a long-term (July 2009-June 2015) retrieved datasets measured by the Greenhouse Gases Observing Satellite (GOSAT), the seasonal cycle and interannual variations of column-averaged volume mixing ratios of atmospheric carbon dioxide (XCO_2) in four fire affected continental regions were analyzed. The results showed that Northern Africa experienced the largest seasonal variations with peak-to-peak amplitude of 6.4 ppm within the year, higher than global mean (2.5 ppm), central South America (3.9 ppm), Southern Africa (5.1 ppm) and Australia (3.0 ppm). The fire CO_2 emissions during fire activity period was found to be a major contributor to the XCO_2 seasonal variabilities. Central South America and Northern Africa recorded 1.67 and 7.50 ppm higher XCO_2 than the global average annually. However, during fire episode, the faster increase of the regional XCO_2 than global mean were noticed during August-October in central South America, Southern Africa and Australia, and October-April of the next year in Northern Africa, extremely higher than those during non-fire episode. Meanwhile, the high aerosol optical depth resulting from the large numbers of fire counts also recorded great increase during fire episodes. The Pearson correlation coefficients between XCO_2 change and fire CO_2 emissions achieved best correlations in Southern Africa (R=0.87, p<0.05). This study revealed that fire CO_2 emissions contributed greatly to the seasonal variations of GOSAT XCO_2 dataset.

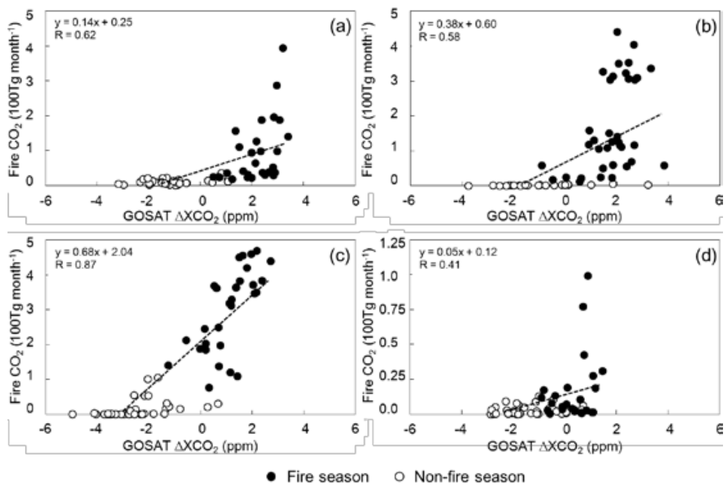

Figure. Scatter plot of monthly GOSAT ΔXCO_2 versus fire CO_2 emissions in four fire affected regions ((a) central South America, (b) Northern Africa, (c) Southern Africa and (d) Australia) during the study period.

Keywords: GOSAT, carbon dioxide, fire emissions, seasonality, interannual variability

Spatio-Temporal Variations Analysis of CH_4 Concentration over East Asia Based on Geostatistics

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Column-averaged CH_4 dry air mole fraction (XCH_4) retrievals from Greenhouse gases Observation SATellite (GOSAT) reveal irregular distribution and lots of gaps in space and time, which make it difficult to directly infer the spatio-temporal variations of XCH_4 and meet the requirements of further scientific research. The aim of this study is to generate regular and high-resolution XCH_4 mapping dataset based on geostatistics, investigate the spatio-temporal distributions and variations of regional XCH_4 and explore the related influence factors. We collect the GOSAT XCH_4 retrievals over East Asia from June 2009 to May 2014. Firstly, we apply the data-driven mapping methodology based on spatio-temporal geostatistics to generate XCH_4 mapping products, with a spatial grid resolution of 1° by 1°and a temporal resolution of 3 days. The leave-one-out cross-validation approach is adopted to evaluate the prediction error, which shows a significant high correlation and a small mean absolute prediction error between observed dataset and prediction dataset. And then the analysis of the XCH_4 spatio-temporal variations present higher XCH_4 values in southern Asia and south-eastern China over all seasons, and an annual mean increase of 5.97 ppb in 5 years. Furthermore, we explore the influences of related ancillary variables to XCH_4 variations, such as the surface emissions and temperature. Preliminary analysis indicates that the dominant role of surface emissions in determining the distribution of XCH_4 concentration in this region and suggesting a promising simple statistical way of constraining surface CH_4 sources and sinks.

Keywords: XCH_4, spatio-temporal variations, geostatistics, GOSAT

Preliminary Assessment of Methane Concentration Variation Observed over Sichuan Basin by GOSAT in China

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Atmospheric column-averaged methane (xCH_4) observations from GOSAT are analyzed to study the spatiotemporal variation of xCH_4 in China. Furthermore, we investigate the driving mechanism of xCH_4 spatiotemporal variations, especially for high xCH_4values shown over Sichuan Basin, by analyzing both the emission mechanism of rice planting process and the regional atmosphere dynamic transportation [1]. The results indicate that spatially the Sichuan Basin presents a higher xCH_4 concentration than other regions in China and is 17 ppb higher than the paddy area in the same latitude zone. Seasonally, xCH_4 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 xCH_4 value during the winter of non-cultivation period when the emissions fromrice paddies are weak and surface air temperature is low. To further investigate the high xCH_4 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 CH_4 accumulation and keep it from diffusion, is one possible reason for the high xCH_4 value in winter.

This work was partly conducted under the framework of the GOSAT RA.

[1] X-C Qin, L-P. Lei, Z-H. He, Z-C. Zeng, M. Kawasaki, M. Ohashi, and Y. Matsumi, “Preliminary Assessment of Methane Concentration Variation Observed by GOSAT in China”, Advances in Meteorology,2015, DOI: 10.1155/2015/125059.

Keywords: GOSAT, Sichuan Basin, rice field, atmosphere transport, driving mechanism

Impact of differences in line parameter databases on GOSAT TIR methane retrieval

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The thermal infrared (TIR) band of Thermal and Near-infrared Sensor for Carbon Observation Fourier Transform Spectrometer (TANSO-FTS) onboard Greenhouse Gases Observing Satellite (GOSAT) observes CH_4 profile at wavenumber range from 1210 cm^{-1} to 1360 cm^{-1} including CH_4 v_4 band. The current retrieval algorithm (V1) uses LBLRTM v12.1 with AER v3.1 line database to calculate optical depth. The purpose of this study is to compare several line parameter databases to assess their impact on CH_4 retrieval: HITRAN2004 database, HITRAN2008 database, AER v3.2 database, and HITRAN2012 database (Rothman et al. 2005, 2009, and 2013. Clough et al., 2005).

The CH_4 line parameters of AER v3.1 and v3.2 databases are based on HITRAN2008 and it updates until May 2009 with line mixing parameters. The line strengths are almost the same between HITRAN2008 and HITRAN2012 in the CH_4 v_4 band, although their line centers are shifted about 0.002 cm^{-1} (Brown et al., 2013). We used LBLRTM v12.2 to calculate optical depth of each layer with wavenumber resolution of 0.0034 cm^{-1} (Clough et al., 2005). We used 2023 spectra observed from March 30, 2010 to September 5, 2011.

At 1247.8 cm^{-1} where there exist three relatively strong CH_4 absorption lines (1247.705 cm^{-1}, 1247.823 cm^{-1}, and 1247.842 cm^{-1}), no H_2O interference, and small N_2O interference, the differences in calculated brightness temperatures between HITRAN2008 and HITRAN2004, between HITRAN2008 and AER v3.2, and between HITRAN2012 and HITRAN2008 were 0.002 K, 0.4 K, and 0.06 K, respectively. The CH_4 vmr retrieved using AER v3.2 was the lowest. Maximum difference of zonal mean of CH_4 vertical profiles between AER V3.2 and HITRAN2008 were 10 ppbv at 500 mbar in latitude range −20° to 20°. This difference was caused by the line coupling of methane. Retrieved difference between HITRAN2000, HITRAN2004 and HITRAN2012 are smaller than 2 ppbv. CH_4 using HITRAN2008 was 5 ppbv smaller than other databases.

Keywords: GOSAT, methane, retrieval, line parameter

Results of the comparison among IASI/METOP-A, GOSAT/TANSO-FTS Band 4 and HIPPO 3 Carbon Dioxide products

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The research project "Application of KLIMA algorithm to CO_2 retrieval from IASI/METOP-A observations and comparison with GOSAT/TANSO-FTS products" has been conducted in response to the Second Research Announcement on GOSAT for the research field "Calibration/Validation", to support the activities of the KLIMA-IASI project funded by the European Space Agency (ESA-ESRIN, Frascati, Italy) and lead by the Institute for Applied Physics "Nello Carrara" of the Italian National Research Council (IFAC-CNR, Sesto Fiorentino, Firenze, Italy). The overall activity aimed at the application of the KLIMA inversion algorithm, integrated into the ESA G-POD (Grid Processing On-Demand) operational environment, to processing of IASI/METOP-A spectra and at the retrieval of carbon dioxide columns and profiles for comparison and cross-validation with GOSAT TANSO-FTS SWIR and TIR products. The activities of comparison and cross-validation were pursued in cooperation with JAXA, NIES and the MoE of Japan. The latter continued beyond the end of the ESA project to exploit the availability of GOSAT operational products from TANSO-FTS measurements in the TIR region. In this work, we present the main results from the final activity of comparison and cross-validation between CO_2 retrieval products obtained from IASI/MetOp-A observations processed by the consolidated version of the KLIMA-IASI/G-POD retrieval code and the operational Level-2 products from Band 4 of TANSO-FTS. We performed a comparison between temporally reduced dataset of collocated IASI, GOSAT TIR and HIAPER Pole-to-Pole Observations (HIPPO) 3 campaign data. We considered CO_2 merged 10-second data retrieved in the HIPPO 3 campaign as reference to evaluate the satellite products. A quantitative analysis of the differences of KLIMA-IASI and GOSAT-TANSO-FTS Band 4 products and HIPPO 3 measurements, taking into account the vertical sensitivity of the remote-sounding measurements from space, has been completed to obtain stringent comparison results.

Keywords: GOSAT, IASI, TIR, carbon dioxide

High Resolution Tropospheric CH_4 and CO Profiles Retrieved from CrIS and TROPOMI

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Profile measurements of CH_4 and CO with sensitivity in the lower troposphere can provide greater sensitivity to surface fluxes than either total column average or mid-tropospheric measurements alone. In addition, quantifying CH_4 and CO concentration vertical distribution helps to mitigate the impact of transport and chemistry uncertainties on estimated surface fluxes. Multi-spectral retrievals, using information from both the 4.6 and 2.3 μm bands for CO, 7.6 and 2.3 μm bands for CH_4, offer improved sensitivity of vertical distribution of CH_4 and CO, especially in the lower troposphere compared to measurements for one spectral region alone. The Cross-track Infrared Sounder (CrIS) instrument on the Suomi-NPP satellite and the TROPOspheric Monitoring Instrument (TROPOMI) aboard the Sentinel 5 precursor (S5p) have the potential to provide the synoptic chemical and dynamical context for lowermost tropospheric CH_4 and CO necessary to quantify long-range transport at global scales. We introduce the JPL MUlti-SpEctral, MUlti-SpEcies, MUlti-SatEllite (MUSES) retrieval algorithm, which ingests panspectral observations across multiple platforms in a non-linear optimal estimation framework. It incorporates the advances in remote sensing science developed during the EOS-Aura era, including the error analysis diagnostics and observation operators needed for trend analysis, climate model evaluation, and data assimilation. Its performance has been demonstrated through prototype studies for multi-satellite missions (AIRS, CrIS, TROPOMI, TES, OMI, and OMPS). We will present the CrIS CH_4 and CO retrievals using measured spectral radiances. Then we will estimate the improvements on both sensitivity and uncertainty reduction when peformaning joint CrIS/TROPOMI retrievals, in comparisons to single instrument retrievals. Consequently, multispectral retrievals show promise in providing continuity with NASA EOS observations and paving the way towards a new advanced atmospheric composition constellation.

Keywords: CH_4, CO, tropospheric profiles, thermal infrared, near infrared, CrIS, TROPOMI

Prescribing fossil fuel emissions in CO_2 source/sink analysis

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The Open-Data Inventory for Anthropogenic Carbon dioxide (ODIAC) is a global high spatial resolution fossil fuel CO_2 emissions ($FFCO_2$) dataset. ODIAC first introduced the combined use of satellite-observed nighttime light (NTL) data and individual power plant emission/geographical location profiles to estimate spatial extents of $FFCO_2$ and it achieved the global emission fields at a 1 × 1km resolution. We have made numerous modifications to the ODIAC emission model since its original publication in 2011 (e.g. emission estimates, emission sectors, emission seasonality and spatial proxy) and the emission dataset has been updated on an annual basis to prescribe $FFCO_2$ in CO_2 simulations supporting the Japanese Greenhouse gases Observing SATellite (GOSAT) and NASA's Orbiting Carbon Observatory 2 (OCO2).As part of the next version of ODIAC, we have started examining the use of NTL data retrieved from the Day/Night Band of the Visible Infrared Imaging Radiometer Suite (VIIRS) on onboard NASA's Suomi National Polar-orbiting Program (NPP) satellite with a hope of improving the current spatial distribution to a 500 × 500 m resolution. The numbers of improvements in the VIIRS instrument over previous Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) instrument (e.g. spatial and temporal resolution, and detection limit) benefit ODIAC in achieving more accurate spatial distributions of emissions and informing their changes in time, with rigorous uncertainty estimates. As a reference in carbon cycle budget analysis, $FFCO_2$ needs to be accurately prescribed in CO_2 simulations because errors associated with $FFCO_2$ thus would be propagated to final flux inverse estimates. We have also constructed a 1 × 1 degree $FFCO_2$ uncertainty map by inter-comparing existing different emission datasets and made an attempt to estimate the potential bias in CO_2 simulations due to errors in $FFCO_2$ prescribed.

Keywords: carbon dioxide (CO_2), fossil fuel CO_2 emissions, nighttime lights, inverse modeling and uncertainty

A 4D-Var inversion system based on the icosahedral grid model (NICAM-TM 4D-Var)

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A four dimensional variational method (4D-Var) is one prominent technique for inverse modeling of atmospheric constituents, but there is still room for growth in researches of applying 4D-Var to atmospheric inversion problems. Using an icosahedral grid transport model and the 4D-Var method, a new atmospheric greenhouse gas (GHG) inversion system has been developed. The system consists of off-line forward and adjoint models and a quasi-Newton optimization scheme. Using the developed system, identical twin experiments were conducted to investigate optimal system settings for an atmospheric CO_2 inversion problem in terms of the adjoint models and the optimization schemes as well as to demonstrate the validity of the developed system. Consequently, it is found that a model set of the forward and adjoint models that have less model errors but have non-linearity performs better than another model set that conserves linearity and exact adjoint relationship. Moreover, the effectiveness of prior error correlations was reconfirmed; the global error had reduced by about 15 % by adding prior error correlations that were simply designed. With the optimal setting, the developed inversion system successfully reproduced spatiotemporal variations of the surface fluxes that span from regional anomalies such as biomass burnings to the continental and the global scales. The optimization algorithm introduced in the system does not require any matrix decomposition that is sometimes a difficult task but necessary to consider correlations among the prior flux errors. This enables us to design the prior error covariance matrix more freely. A future study with the developed inversion system and a sophisticated prior error covariance would exploit satellite observations and provide valuable information of GHG flux variation mechanisms.

Keywords: carbon dioxide, inversion, 4D-Var

Potential clear-sky bias in flux inversions of carbon dioxide based on satellite measurements

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One of the most puzzling features of flux inversions of carbon dioxide based upon first GOSAT, and now OCO-2 measurements, is the fundamental redistribution of fluxes compared to estimates based on surface measurements alone. Across different models and retrievals, some consistent differences are seen: the Tropics become a larger source (or lesser sink) and the extratropics become a larger source, particularly in Europe. These differences are often so large that the surface-based and satellite-based flux results are no longer consistent within uncertainty bounds. Some studies have attributed this redistribution of fluxes to biases in the measurements, perhaps due to aerosols, or the result of inappropriately defined prior covariance assumptions in the satellite retrieval. One aspect that has not been explored thoroughly is the possibility that this difference might be the result of a clear-sky bias in the measurements, such that the measurements are systematically skewed towards period of higher (seasonal) uptake. Analysis of flux tower data and upscaled flux products shows the effect of this to be regionally dependent with a strong seasonal signal, resulting in an overestimation in uptake in the northern hemisphere extratropics. The diagnostic biosphere model VPRM (Vegetation Photosynthesis and Respiration Model) is used in conjunction with mesoscale simulations to assess this effect in concentration space. The inferred offset in XCO2 is estimated, and the impact on inverted fluxes is shown. Potential strategies to overcome such a systematic bias are discussed.

Keywords: GOSAT, carbon dioxide, flux inversion

GOSAT CO_2 Inversion Inter-comparison Experiment Phase-II

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Atmospheric inversion, a technique for estimating surface fluxes of trace gases from atmospheric measurements, has been used in attempts to gain insight into how the stocks and flows of carbon over the globe are being modified. To further gain a process-level understanding of these modifications, it is important to evaluate, understand, and subsequently reduce the uncertainty that arises through the measurements and the flux estimation processes. For the evaluating and understanding purposes, the TransCom inversion inter-comparison studies were held in the late 1990s, and more recently after the advent of satellites dedicated for GHG monitoring, GOSAT inversion inter-comparison (Phase-I) was carried out. The latter evaluated the largest possible spread of GOSAT-based CO_2 flux estimates by allowing the study participants to use inversion systems and GOSAT column-mean CO_2 (X_{CO2}) retrieval datasets of their choice. This study was also accompanied by another inter-comparison that used a single estimation system to evaluate the degree to which differences in available five independent GOSAT X_{CO2} datasets can impact flux estimates. The spreads (SD) of regional fluxes found in these studies were 0.4 and 0.3 GtC/yr, respectively.

The second phase of the GOSAT inversion inter-comparison is designed to explore differences in existing inversion systems and evaluate their impact on CO_2 flux estimates as uncertainty in flux estimation. For this, the participants are asked to use a common input dataset that consists of a single GOSAT X_{CO2} retrieval dataset and an a priori flux dataset. The second phase study takes advantage of a five-year-long analysis period (2009-2014) during which GOSAT X_{CO2} retrievals are continually available, to observe how similarly or differently each inversion estimation reacts to major weather events of heat waves, droughts, and heavy precipitations occurred mostly between 2010 and 2011. More descriptions are given in this presentation.

Keywords: Atmospheric inversion, modeling, CO_2, GOSAT, inter-comparison

Analysis on Uncertainties in Regional CO_2 inversions from GOSAT XCO_2 Retrievals

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GOSAT XCO_2 retrievals have been used toward improving surface CO_2 flux estimates. One of the challenges is systematic errors in XCO_2, retrievals, which may lead to differences in spatial/temporal variations of inverted CO_2 flux. In this study, we investigate the impact of GOSAT XCO_2 on the spatial distribution of estimated CO_2 fluxes, by conducting inversion with combinations of surface measurements and several sets of bias-corrected GOSAT XCO_2. The results show that the global land-ocean partitioning of annual CO_2 fluxes and also their spatial distributions vary with XCO_2 dataset. The inversions with the variable bias-corrected XCO_2 using multiple linear regression yields a reasonable global ocean CO_2 uptake while the inversion with the uniformly bias-corrected XCO_2 estimates unrealistically large ocean CO_2 uptake of ~4 GtC yr^{-1}, especially in the Southern Hemisphere. This result suggests the variable bias correction is effective in minimizing the systematic biases in the ocean sunglint XCO_2 retrievals. However, the inversion of the both bias-corrected XCO_2 data obtains larger North-South gradient of land CO_2 flux estimates in the Northern Hemisphere by >1 GtC yr^{-1} than the inversion with surface measurements only. This increased gradient is mainly attributed to biases in XCO_2 observed with M-gain mode over bright surfaces (over the other land surfaces, H-gain mode is used), which results in unrealistically high CO_2 emissions in the M-gain areas around the Middle East. M-gain XCO_2 appears to impact the regional flux estimates in the low latitudes (tropical regions), extensively far beyond the M-gain areas. To improve the surface CO_2 flux estimates on a regional scale, it is necessary to characterise the respective errors in flux estimates from H-gain and M-gain XCO_2 and minimize the biases in XCO_2 retrievals.

Keywords: GOSAT, carbon dioxide, bias correction, inverse model, surface flux estimation

Evaluations of 1km grid Global Terrestrial Carbon fluxes

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Estimating global terrestrial carbon fluxes with high accuracy is important to understand global environmental changes. Moreover the estimations with 1km grid resolution may contribute to policy makers and other social activities. In order to reveal the present state of terrestrial carbon fluxes covering a wide range and a decadal scale, using the satellite-based diagnostic biosphere model is suitable because of uniformly observing on the present global land surface condition. But the diagnostic model can use only a few decades of data, and have the potential to underestimate the annual terrestrial carbon fluxes as a result of doing spin-up to the steady state. In this study, we optimized the spin-up time of the terrestrial biosphere model (BEAMS) in each sub continental region using estimations of carbon fluxes by the atmospheric transport model (GOSAT L4A global CO_2 flux). Furthermore we estimated the 1km grid global terrestrial carbon fluxes. Significant improvement of the estimation accuracy was achieved by using the two satellite observation data (GOSAT as atmospheric information, and MODIS as land surface information). We evaluated our new carbon flux estimations on various spatial scales. Annual global carbon fluxes were indicated similar values between BEAMS, GOSAT L4A, and GCP estimations, and perhaps these may be reasonable. In a tropical regions that are low satellite observation data, the accuracy of carbon fluxes remained a matter of discussion.

Keywords: Terrestrial carbon flux, BEAMS, GOSAT L4A

The simulation of TanSat measurements in terrestrial CO_2 flux estimation

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Chinese Global Carbon Dioxide Observation Satellite (TanSat) will be launched in the end of 2016 and monitor the sources and sinks of carbon dioxide (CO_2) over global. This study shows the potential contribution of TanSat measurements on the land surface carbon flux estimation by using an Ensemble Kalman Filter (EnKF) assimilation method. After data assimilation, the uncertainty reduces by 80%, and gets a posteriori bias about 0.34 GtC/yr over land. The 16-day nadir and 16-day glint observation cycle is not enough to capture sufficient data to constrain sources and sinks of CO_2. We investigate the possible advantage observation mode that including: single orbit alternative mode (e.g. nadir and glint), flexible change between nadir and glint mode depends on the footprint surface type, joint measurements following another satellite with complementary mode, and joint nadir measurements in an alternative orbit. The results demonstrate that joint measurements following another satellite with complementary mode can provide more precise posteriori flux, which indicates the advantage of cooperation in CO_2 measurements from space.

Keywords: TanSat, carbon dioxide, flux, assimilation, EnKF

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

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Inverse analysis is effective in estimating the flux of greenhouse gases 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. 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. 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. The distinctive 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, CO_2 flux, land surface element, GOSAT, South America, Africa

Study of the footprints of short-term variation in XCO_2 observed by TCCON sites using NIES and FLEXPART atmospheric transport models

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The Total Carbon Column Observing Network (TCCON) is a network of ground-based Fourier Transform Spectrometers (FTS) that record near-infrared (NIR) spectra of the Sun. From these spectra, accurate and precise observations of CO_2 column-averaged dry-air mole fraction (denoted XCO_2) are retrieved. TCCON FTS observations have previously been used to validate satellite estimations of XCO_2; however, our knowledge of the short-term spatial and temporal variations in XCO_2 surrounding the TCCON sites is limited.

In this work, we use the National Institute for Environmental Studies (NIES) Eulerian three-dimensional transport model and the FLEXPART (FLEXible PARTicle) Lagrangian Particle Dispersion Model (LPDM) to determine the footprints of short-term variations in XCO_2 observed by operational, past, future, and possible TCCON sites. We propose a footprint-based method for the colocation of satellite and TCCON XCO_2 observations, and estimate the performance of the method using the NIES model and five GOSAT XCO_2 product datasets. Comparison of the proposed approach with a standard geographic method shows higher number of colocation points and average bias reduction up to 0.15 ppm for a subset of 16 stations for the period from January 2010 to January 2014. Case studies of the Darwin and La Réunion sites reveal that when the footprint area is rather curved, non-uniform and significantly different from a geographical rectangular area, the differences between these approaches are more noticeable. This emphasizes that the colocation is sensitive to local meteorological conditions and flux distributions.

Keywords: GOSAT, carbon dioxide, XCO_2, TCCON, colocation, validation

Inverse modeling of CO_2 and CH_4 surface fluxes using GOSAT observations – Level 4 product updates and developments

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Greenhouse gases Observing SATellite (GOSAT) Level 4 (L4) products – monthly regional surface CO_2 and CH_4 flux estimates by inverse modeling from GOSAT column-averaged dry-air mole fractions and ground-based observational data by Globalview and WDCGG datasets now cover the 3-year period starting from June 2009. The fluxes were optimized for 64 regions for CO_2 and 43 regions for CH_4. The L4 CH_4 product was extended till September 2013 using the recent version of EDGAR methane emission inventory dataset and an extension of GFED v3.1 fire emissions dataset. The CH_4 model simulation was able to successfully reproduce the seasonal and synoptic scale variability observed at continuous observation sites. To extend the Level 4 CO_2 product to 2013, a development was made to use event observation data from Globalview-plus dataset instead of smoothed and filtered Globalview-CO_2 data. The products provide an opportunity to study the interannual flux variability including events of CO_2 and CH_4 emissions from large-scale climate anomalies and forest fires in Russia and Amazonia in 2010. Additionally, a new grid-scale inversion technique based on the adjoint of an Eulerian-Lagrangian coupled transport model was developed and applied to the inverse modeling of weekly surface CO_2 fluxes at 1°×1° resolution using GOSAT and ground-based observation data for 2009-2012 period. The seasonal cycle of CO_2 exchange estimated with new inverse model is consistent with one estimated by currently used region-based approach.

Keywords: GOSAT, carbon dioxide, methane, inverse modeling

Quantifying global and regional methane budget by inverse modeling

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Methane is the second most important greenhouse gas after the carbon dioxide, but it is 25 times more effective in contributing to the radiative forcing than CO_2.

Since 2009, global dry air column-averaged mole fractions are measured from space by the Thermal And Near Infrared Sensor for carbon Observations-Fourier Transform Spectrometer (TANSO-FTS), on-board the GOSAT satellite.

TANSO-FTS is a nadir looking Fourier transform spectrometer, observes sunlight reflected from the earth's surface and light emitted from the atmosphere and the surface.

Inverse modeling using chemical transport model and measurements from space has been widely used to quantify emissions of atmospheric trace gases. In this study, we used NIES (National Institute for Environmental Studies) retrievals in the short wave infrared radiation (SWIR) covering five years of observations, from January 2010 to December 2014, in order to estimate global methane fluxes by PYVAR-LMDZ model.

The PYVAR-LMDZ model is based on the Bayesian theory which combine observations and model, to estimate sources and sinks of atmospheric compounds. The system iteratively minimizes a cost function, and provides the best linear unbiased estimate of fluxes, which are averaged at eight-day periods in each grid cell of the model (3.75°x2.3°).

Results show a decreasing of methane global emissions in 2011, this decreasing is more significant between 30°N and 60°N, whereas an increasing is seen from 2012 to 2014.

We will present the results of global and regional methane budget, and its inter-annual variability.

Enhanced methane emissions from Amazonian drought

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The Amazon is a significant source of atmospheric methane, but little is known about the source response to increasing drought severity and frequency. We investigated satellite observations of atmospheric column-averaged methane for 2010 drought and 2011 wet years using an atmospheric inversion scheme. Our analysis indicates an abrupt increase in atmospheric methane over the southern Amazon during the drought, representing an increase in annual emissions relative to the wet year. We attribute the increase to emissions from biomass burning driven by intense drought, combined with carbon monoxide showing seasonal variations correspond to the methane variations. We show that there is probably a strong correspondence between drought and methane emissions in the Amazon.

Keywords: Amazonian drought, methane emissions, biomass burning, GOSAT

MicroCarb performances assessment

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Decision to conduct the MicroCarb program has been announced by the French government in December 2015, in the frame of the COP-21. MicroCarb is thus the first European mission dedicated to atmospheric Carbon dioxyde monitoring from space. MicroCarb is a sampling mission which relies on original techniques in order to make accurate measurements from an affordable micro satellite, and targets a launch in 2020. It will then provide continuity of monitoring data after OCO-2, Tansat and GOSAT-2 missions, and also contribute to prepare and develop the skills which are necessary for future operational missions.

A first presentation (Author: F. Buisson) gives a general introduction to the MicroCarb program (objectives, organization, overall characteristics and performances, current status), and a second one (Author D. Pradines) gives a technical insight (optical design, calibration strategy, pointing modes…). Here a poster presents the requirements, the performance assessment rationale, and the first results with the optical concept.

We will first present a performance budget on calibrated spectra (level 1), including the radiometric, spectral, geometric and polarimetric aspects. We will then present the error budget on CO_2 and CH_4 concentrations (level 2) from the list of the different error contributors (either from instrumental or geophysical origin), and making difference between random and systematic errors. For that purpose, we apply an optimal estimation in several geophysical conditions for the instrumental baseline design. Finally, the fluxes performances retrievals (level 4) will also be presented, especially taking advantage of a new pointing mode allowing acquisition of several distant measurements across the spacecraft on-ground track.

Finally, as the optical concept offer a great flexibility regarding the number and position of spectral bands, the poster will show how the performance analysis contributes to the choice of MicroCarb spectral bands.

Keywords: MicroCarb, carbon dioxide, microsatellite

Plan of the GOSAT-2 FTS SWIR products and its preliminary sensitivity study

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The Greenhouse gases Observing SATellite (GOSAT) was launched in January 2009 and observed global distribution of the column-averaged dry air mole fractions of carbon dioxide and methane (XCO_2 and XCH_4) for about seven years. As a successor mission to the GOSAT, GOSAT-2 is planned to be launched in early 2018, and its critical design review (CDR) was completed. GOSAT-2 also has a Fourier transform spectrometer (FTS) like GOSAT to obtain short-wavelength infrared (SWIR) light reflected from the earth's surface and thermal infrared (TIR) radiation emitted from the ground and atmosphere. According to the current design of the FTS-2 (FTS onboard the GOSAT-2), its SNR is higher than or almost equal to that onboard the GOSAT, and it covers the 2.3 μm carbon monoxide (CO) band as well as the 1.6 and 2.0 μm CO_2 bands and 1.67 μm CH_4 band. The SWIR Level 2 retrieval algorithm for GOSAT-2 is developing based on the latest full-physics based retrieval algorithm for GOSAT. Our preliminary sensitivity test shows that the SNR improvement in SWIR bands reduces the retrieval random error (precision) about 15% for XCO_2 and 35% for XCH_4 than those of GOSAT. In addition to the full-physics based XCO_2, XCH_4, XH_2O, and XCO products, we are planning to provide the proxy-based XCH_4 products as well as solar induced chlorophyll fluorescence products.

Keywords: GOSAT-2, SWIR, retrieval

An Update on the TANSO-FTS-2 Instrument for GOSAT-2

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Harris is now building the next-generation interferometric instrument for the second Greenhouse Gases Observing Satellite, or GOSAT-2. The instrument is called the Thermal And Near-infrared Sensor for carbon Observation (TANSO) Fourier Transform Spectrometer (FTS), or TANSO-FTS-2. The TANSO-FTS-2 instrument measures upwelling earth radiance in multiple spectral bands ranging from 755nm to 14.3 microns. This data is used to determine atmospheric concentrations of carbon dioxide and methane, which are critical greenhouse gases, on a global basis. It is a critical asset for the monitoring and trending of greenhouse gases which contribute to global warming.

Harris' TANSO-FTS-2 instrument includes a number of new design features intended to improve mission performance. In particular, a new Intelligent Pointing camera system is used to identify cloud-free locations within the field of view, and the instrument's line of sight is autonomously adjusted to collected hyperspectral data from this location. This is expected to greatly increase the yield of useful earth observations, uncontaminated by effects from clouds. Another improvement is a comprehensive set of onboard calibration targets that are used to accurately calibrate the instrument over its entire spectral range. Other improvements include a larger aperture for improved SNR, improvements to the interferometer to ensure high data quality throughout mission life, and an improved scanning system with excellent line of sight stability.

This paper will briefly summarize the GOSAT-2 mission, the requirements for the TANSO-FTS-2 instrument, and the TANSO-FTS-2 instrument design. It will then summarize the development status of the instrument.

Keywords: GOSAT, FTS, interferometer

CO_2 Sounder lidar multi-wavelength approach: Retrievals for airborne and space measurements, column water vapor measurements

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The NASA Goddard Space Flight Center (GSFC) CO_2 Sounder measures the CO_2 mixing ratio using a pulsed multi-wavelength integrated path differential absorption (IPDA) approach. Compared to passive CO_2 sensors, such as those aboard GOSAT and OCO-2 satellites, active (lidar) remote sensing measurements offer many advantages including low sun angle and night coverage, robustness against aerosol and cloud contamination, precise range resolution, and column measurements to cloud tops.

The CO_2 Sounder multi-wavelength approach has advantages compared to two-wavelength on/off-line lidar measurements. These include bias control, water vapor measurements and the vertical CO_2 information content in the lineshape. However, the multi-wavelength measurement also needs a more complex retrieval algorithm to best use all the information present in the lineshape. In this presentation, we describe: (1) Retrieval algorithm of the CO_2 Sounder measurements and airborne instrument calibration (2) Error analysis of the retrieval approach and the implications on space scaling (3) Lidar column water vapor measurements using a HDO absorption line that occurs next to the CO_2 absorption line. The resulting estimates in water vapor column can reduce the uncertainty in the dry air column used in X_{CO2} retrievals.

Keywords: ASCENDS, carbon dioxide, retrieval, lidar, airborne, spectroscopy, boundary layer

Airborne Lidar Measurements of Atmospheric Column CO_2 Concentration to Cloud Tops during ASCENDS Science Campaigns

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Globally distributed atmospheric CO_2 concentration measurements with high precision, low bias and full seasonal sampling are crucial to advance carbon cycle sciences. However, two thirds of the Earth's surface is typically covered by clouds, and passive remote sensing approaches from space, e.g., The Orbiting Carbon Observatory (OCO-2) and The Greenhouse gases Observation SATellite (GOSAT), are limited to cloud-free scenes. Thus, passive approaches have limited global coverage and poor sampling in cloudy regions, even though some cloudy regions have active carbon surface fluxes.

NASA Goddard is developing a pulsed integrated-path, differential absorption (IPDA) lidar approach to measure atmospheric column CO_2 concentrations from space as a candidate for NASA's Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) mission. Measurements of time-resolved laser backscatter profiles from the atmosphere also allow this technique to estimate column CO_2 and range to cloud tops in addition to those to the ground with precise knowledge of the photon path-length. This allows retrievals of column CO_2 concentrations to cloud tops, providing much higher data coverage and some information about vertical structure of CO_2. This is expected to benefit atmospheric transport process studies, carbon data assimilation in models, and global and regional carbon flux estimation.

We show some preliminary results of the all-sky retrieval capability using airborne lidar measurements from past ASCENDS airborne science campaigns on the NASA DC-8, including 2016. These show retrievals of atmospheric CO_2 over low-level marine stratus clouds, cumulus clouds at the top of planetary boundary layer, some mid-level clouds and visually thin high-level cirrus clouds. The CO_2 retrievals from the lidar are validated against in situ measurements and compared to the Goddard Parameterized Chemistry Transport Model (PCTM) simulations. Lidar cloud slicing to derive CO_2 abundance in the planetary boundary layer and free troposphere also has been demonstrated. The capability of future lidar missions to measure CO_2 above clouds will be particularly valuable for the regions with persistent cloud covers, e.g, the Intertropical Convergence Zone, the west coasts of continents with marine layer clouds and the Southern Ocean, which has the highest occurrence of low-level clouds.

Keywords: ASCENDS, carbon dioxide, clouds, retrieval, lidar, backscattering