Abstract Collection

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Global space-based observations of CO_2:

From SCIAMACHY to CarbonSat

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A decade of new SCIAMACHY XCO_2 retrievals will be presented covering the entire lifetime of ENVISAT. The SCIAMACHY time series is currently being extended with GOSAT. In the context of the ESA Climate Change Initiative (CCI) project GHG-CCI several XCO_2 products from SCIAMACHY and GOSAT have been compared and the status of this activity will also be presented. This includes the merged ensemble product generated with the Ensemble Median Algorithm "EMMA". To further extend this time series, Carbon Monitoring Satellite (CarbonSat) has been proposed by IUP, Univ. Bremen. CarbonSat has been selected by ESA as one of two candidate missions for Earth Explorer 8 (EE8) to be launched around the end of this decade. For CarbonSat error analysis results will be presented focusing on nadir mode observations over land. A one year data set of simulated CarbonSat XCO_2 and XCH_4 observations has been generated to assess the CarbonSat performance. The data set will be presented focusing on an assessment of systematic errors due to aerosols and cirrus clouds.

As a first application the data set has been used to assess how well the anthropogenic CO_2 emission of a large city can be inferred from single overpass CarbonSat "XCO_2 images" using Berlin, the capital of Germany, as an example.

Keywords: SCIAMACHY, GOSAT, CarbonSat, carbon dioxide, retrieval

Progress of GOSAT Project in 2012 and 2013

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The Greenhouse gases Observing SATellite (GOSAT) has been in orbit for more than four years, and the observational data has been acquired nearly seamlessly since June 2009. Along with the data values stored in GOSAT TANSO-FTS SWIR Level 2 data products, the column averaged dry air mole fraction of CO_2 and CH_4, retrieved from TANSO-FTS SWIR Level 1B radiance spectral data, are now made available by several different institutes around the world. These column concentration data are validated by comparing with reference data collected at TCCON FTS sites. Two of the major data products of the GOSAT project, Level 4A (monthly CO_2 source/sink maps) and Level 4B (3-D distribution of CO_2 concentrations) data products, were released in December 2012. TANSO-CAI Level 3 NDVI products were also released in 2012. Some aspects on seasonal variations and annual trends of CO_2 and CH_4, and tendencis of their regional monthly fluxes have been seen from the GOSAT data products. We herein summarize the main accomplishments made in the GOSAT Project in 2012 and expected progress in 2013. Also, the current status of ongoing researches being conducted within the framework of the GOSAT Research Announcement will be reported.

The OCO-2 Mission – the Next Step in Space-Based CO_2 Measurements

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The EnviSat SCIAMACHY and GOSAT missions have firmly established the value of space based, solar, remote sensing observations of atmospheric carbon dioxide (CO_2). However, the restricted coverage of the oceans and high latitude continents by these sensors has limited their impact on CO_2 flux inversion studies. Once it has been deployed in the 705-km Afternoon Constellation in late 2014, the NASA Orbiting Carbon Observatory-2 (OCO-2) will address these shortcomings. The OCO-2 spacecraft carries and points a 3-channel, imaging, grating spectrometer that is optimized for sensitivity and coverage. While its spectral channels overlap the GOSAT TANSO-FTS solar channels and have comparable spectral resolution, the OCO-2 instrument was designed to collect 24 soundings per second along a narrow swath, yielding 96 times as many soundings over the illuminated hemisphere. The high signal to noise ratio and small (< 3 km^2) sounding footprint should yield more useful soundings in partially cloudy or topographically rough regions. These capabilities, combined with the spacecraft's ability to observe the bright ocean glint spot over the entire sunlit hemisphere, are expected to yield far better coverage than earlier missions. However the OCO-2 instrument will pose some unique challenges for calibration. This presentation will summarize the OCO-2status and plans.

Keywords: Orbiting Carbon Observatory – 2, OCO-2, CO_2

The Status of Chinese Carbon Dioxide Observation Satellite (TanSat)

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The Chinese carbon dioxide observation satellite (TanSat) project is one of the national high technology research and development programs. Two instruments will be onboard the TanSat, the main instrument is a high resolution grating spectrometer that measure reflected sunlight with the 0.76 μm O_2 A-band and two CO_2 absorption bands at 1.61 and 2.06 μm. The second instrument is the Cloud and Aerosol polarization Imager (CAPI), which is a wide field of view moderate resolution imaging spectrometer, it include 0.38, 0.67, 0.87, 1.375 and 1.64μm channels, with polarization channels in 0.67μm and 1.64μm.

Currently, the preliminary design review (PDR) of TanSat was finished. The preliminary designed spectral sampling rate and range for CO_2 grating spectrometer have been modified to avoid undersampling problem. The on board solar calibration will be added and work together with lunar calibration for Cloud and Aerosol polarization Imager (CAPI). A XCO_2 retrieval algorithm has been developed with adequate accuracy and it has been applied to retrieve XCO_2 from GOSAT L1B data. The algorithm will serve as operational level 2 data processor for TanSat. A CO_2 flux inverse system is under developed and regional CO_2 source and sink will be derived from XCO_2 observations.

Ground based observation network had been established and observed around China to validate satellite observation of CO_2, which include three Bruker IFS125 and three Optical Spectrum Analyzers. The initial prototypes of the two instruments are under manufactured, the final prototypes will be finished on Oct. 2014, launching and on-board testing are scheduled from June 2015.

Lessons and Learned from GOSAT towards GOSAT-2

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To observe the global column concentration of carbon dioxide (CO_2) and methane (CH_4) from space, the Greenhouse gases Observing SATellite (GOSAT) was launched on January 23, 2009, and has started the operational observation. Thermal and Near Infrared Sensor for Carbon Observation – Fourier Transform Spectrometer (TANSO-FTS) has been continuously measuring CO_2 and CH_4 distributions globally, and the retrieved column CO_2 and CH_4 data have been distributed to the public. Over four-years operational periods, the useful scientific data sets and interesting articles for carbon source/sink evaluation were produced and published, and these results have been supporting to well understanding of carbon cycle. Currently, the importance of space-based carbon observation has been approved and desired the continuous observation in toward. Through the TANSO-FTS operation with the radiometric, geometric and spectroscopic characterizations, we learned how to improve the accuracy of XCO_2 and XCH_4 based on short-wavelength FTS. To elucidate the carbon cycle more precisely, our experiences have to be summarized and applied in the future missions. To continue and improve the space-based carbon monitoring, the conceptual design work of GOSAT-2 has been started. The science and technical highlight of GOSAT and the preliminarily design of GOSAT-2 will be presented with current status.

Keywords: GOSAT, GOSAT-2, carbon dioxide, methane

Status of the CNES / MicroCarb small satellite for CO_2 measurement

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CNES is currently completing the preliminary analysis of the MicroCarb program, an upcoming exploratory mission dedicated to the fine measurement of the atmospheric CO2 content. The knowledge of Carbon exchanges between the different sources (human activities or natural processes) and reservoirs (atmosphere, oceans, vegetation and soils) is one of the scientific priorities for a better understanding and prediction of climate changes. The global and repetitive measurement from space combined with a global transport model can provide the missing global information on regional CO2 sources and sinks. MicroCarb will demonstrate that a high level of performance can be obtained through a small satellite (<200 kg) with reduced cost. Microcarb is based on a grating spectrometer with three spectral bands (0.76 µm, 1.6 µm and 2.0 µm). The CO2 column concentration will be retrieved from the spectra by a classical optimal estimation technique. The instrument will be either carried by a Myriade micro-satellite platform or available as an autonomous payload. Phase A is now being completed and permits to conclude to the technical feasibility of the program.

Keywords: Microcarb, carbon dioxide, retrieval, micro-satellite, CNES

CarbonSat, ESA's Earth Explorer 8 Candidate:

Mission Overview

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Within ESA's Earth Observation Envelope Programme, two candidate missions, called FLEX and CarbonSat, have been selected as candidates for ESA's eighth Earth Explorer mission.

CarbonSat aims to deliver global data sets of dry-column mixing ratios of CO_2 and CH_4 with high precision (goal: CO_2 < 1 ppm, CH_4 < 9 ppb for a single ground scene observation) and accuracy. These quantities will be retrieved from high spectral resolution, high signal-to-noise ratio measurements of reflected sunlight in the CO_2 bands near 1.6 μm and 2.0 μm, the O_2 A-band near 765 nm, and the CH_4 band near 1.65 μm. A high spatial resolution (2 x 2 km^2) and a broad swath (larger than 180 km) will allow global imaging of localized strong emission sources and enables the separation of anthropogenic from natural sources and sinks. CarbonSat's coverage will provide an order of magnitude larger number of cloud free measurements than any of the current generation of space-based greenhouse-gas instruments on GOSAT, OCO-2 and OCO-3. In 2012 CarbonSat entered its industrial system feasibility activities, which are complemented by scientific studies and campaigns.

The mission overview with its observational requirements and current status of mission concepts will be presented.

Keywords: CarbonSat, carbon dioxide, methane, mission requirements, ESA

NASA’s planned GHG missions and timelines

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Since the selection of the original Orbiting Carbon Observatory (OCO) through the last of the Earth System Science Pathfinder solicitations, NASA has been seriously investing into global greenhouse gas observations from satellites. The 2007 National Research Council Decadal Survey for Earth Science recommended that NASA follow up OCO with an active sensing mission for CO2 observation and outlined the ASCENDS mission. Since that time, the original OCO mission failed to reach orbit, and the budget scenario to enact the Decadal Survey did not materialize as hoped by the NRC committee. NASA prepared a climate continuity plan to the US government that would allow for distinct plans for all of Earth Science, including greenhouse gas observations. This plan for the next decade includes OCO-2, OCO-3 (to be implemented on the ISS), and ASCENDS. Furthermore, the plan includes significant investment into Venture Class investigations, allowing new ideas with lower budgets to be advanced in a competitively selected framework.

Keywords: NASA, OCO, ASCENDS, Decadal Survey

The Proposed OCO-3 Mission

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As part of the Orbiting Carbon Observatory-2 (OCO-2) mission, NASA authorized the development of a flight spare instrument. If this instrument is not needed for OCO-2, it will be available as a stand-alone instrument for a mission of opportunity. NASA has recently approved a proposal to install this instrument on the International Space Station (ISS). Because the core of the proposed OCO-3 instrument would be assembled from OCO-2 instrument flight spares, it is expected to have similar sensitivity and performance characteristics as OCO-2. However, a few modifications will be required to adapt this instrument from the agile, dedicated, OCO-2 spacecraft bus to the nadir-pointing ISS platform. These changes included the addition of an agile, 2-axis pointing mechanism, and new approach for compensating for the strong polarization dependence of the instrument. While these new capabilities add complexity to the instrument, the new pointing mechanism could provide new opportunities for mapping compact targets, such as cities, power plants, or coastlines. All OCO-3 instrument changes would be designed to minimize impacts to the OCO measurement precision requirement of 1 ppm in X_{CO2} on 1000 km scales at monthly intervals. We will provide a brief overview of the mission, projected sampling patterns, and proposed timeline.

Keywords: OCO-2, OCO-3, carbon dioxide, mission status

Recent Advancements in Airborne Laser

CO_2 and O_2 Column Measurements

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This paper discusses the latest flight test results of an intensity-modulated (IM) continuous-wave (CW) laser absorption spectrometer (LAS) that simultaneously operates near 1.57 □m for remote CO_2 column measurements and near 1.26 □m for remote O_2 column measurements. This IM-CW LAS system is under development for a future space mission to determine the global distribution of regional-scale CO_2 sources and sinks, which is the objective of the NASA Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) mission. A prototype of this system was most recently evaluated for CO_2 and O_2 column measurements during the 2011 and 2013 ASCENDS DC-8 flight-test campaigns. This paper discusses the precision of the MFLL CO_2 column measurements observed over widely different surfaces during these campaigns with a demonstrated measurement precision of better than 0.1% (<0.4 ppm) for a 10-s average. The absolute accuracy of the MFLL CO_2 column measurements was evaluated in comparison with airborne *in situ* CO_2 measurements, and it was found to be within 0.44% (~1.7 ppm). MFLL O_2 column measurements were initiated during the 2011 flight campaign and showed expected O_2 column variations with altitude. The most recent ASCENDS flight test campaign was conducted in February-March 2013, and the latest MFLL CO_2 and O_2 column performance and ranging results will be presented in this paper.

Keywords: ASCENDS, lidar, carbon dioxide, laser absorption spectrometer

Pulsed Lidar Measurements of Atmospheric CO_2 Column Absorption, Range and Surface Reflectivity in the ASCENDS 2013 Airborne Campaign

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We have previously demonstrated an efficient wavelength-resolved IPDA lidar technique for measuring range and the tropospheric CO2 column density as a candidate for NASA's ASCENDS mission. Our pulsed airborne lidar samples shape of the 1572.33 nm CO2 absorption line using 250 mW average laser power, 30 wavelength samples per scan and 300 line scans per second.

Our team participated in the February 2013 ASCENDS flight campaign on the NASA DC-8 aircraft, flying over a variety of surfaces in the US, including over Railroad Valley NV, the California Central Valley, desert areas in Arizona, and over cold snow fields in the Rocky Mountains of Colorado and warmer snow in Iowa and Wisconsin. Most flights had several altitude steps over the same terrain up to altitudes of >12 km. Clear CO2 line shapes were observed at all altitudes. Our post-flight analyses showed that the retrievals of lidar range, line fits and CO2 column absorption worked well when measuring over topography with rapidly changing height and reflectivity, and through thin clouds. As expected, the relative reflectivity of snow surfaces was small, about 10% of that of the desert. An overview of the approach and examples of the 2013 measurements will be presented.

Keywords: carbon dioxide, IPDA, lidar, ASCENDS

Modeling of Space Laser Absorption Spectrometry for Atmospheric CO_2 Column Measurements

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Accurate global observations of atmospheric carbon dioxide (CO_2) through the space mission of Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) are crucial to improving our understanding of CO_2 sources and sinks. This study focuses on modeling of the performance of CO_2 laser absorption spectrometer (LAS) systems and their CO_2 column measurements. The model accounts for all fundamental physics of the instruments and their related CO_2 measurement environments. The modeled instruments are assumed to be intensity-modulated (IM), continuous-wave (CW) LAS systems operating in the 1.57 μm CO_2 absorption band as the Exelis's airborne Multifunctional Fiber Laser Lidar. Measurement simulations demonstrate good agreement with airborne test results. The difference between modeled and measured signal-to-noise ratios (SNR) of LAS CO_2 column optical depths (τ_d) is generally within 20%. The simulations for spaceborne τ_d measurements indicate that with 50 W transmitted laser power, the accuracy of τ_d estimates will be less than 0.2% for 10-s (~70 km) horizontal averages. Under thin cirrus conditions, the SNR of τ_d measurements with 0.1-s integration period over playa surfaces will exceed 60. These results indicate that the current space IM-CW LAS instrument design will meet the basic ASCENDS science requirements.

Keywords: ASCENDS, carbon dioxide, laser absorption spectrometer, modeling, comparison

Quasi-geostationary observations of CO_2 from a highly elliptical orbit (HEO): a potential method for monitoring northern CO_2 fluxes

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Geostationary satellites have the potential to observe atmospheric CO_2 with unprecedented temporal coverage, but are limited to ~60°N-60°S latitude, thus excluding the northernmost Boreal forests and the Arctic. A highly elliptical orbit (HEO) offers the potential for quasi-geostationary observations of these high latitude regions. Canada's proposed Polar Communications and Weather (PCW) mission would consist of two satellites in HEOs, optimized for observing northern high latitudes (~50-90°N). Although the primary mission drivers are Arctic weather and communications, a mission enhancement consisting of an imaging Fourier transform spectrometer (FTS) operating in the thermal and near-infrared. NIR CO_2 and CH_4 bands in the 5990-6257 cm^{-1} region (0.25 cm^{-1} resolution) and the O_2 A band at 13060-13168 cm^{-1} (0.5 cm^{-1} resolution) would enable retrieval of XCO_2 and XCH_4. We report on an observing system simulation experiment (OSSE) to compare the efficacy of NIR CO_2 observations from PCW and GOSAT for constraining northern high latitude CO_2 fluxes by inverse modelling. Our results demonstrate that HEO observations offer improved constraints on regional-scale northern CO_2 fluxes. Disentangling the CO_2 fluxes from vegetation and permafrost thaw would remain a challenge, but supporting measurements such as chlorophyll fluorescence in the O_2 band could provide useful information to address this problem.

Keywords: carbon dioxide, FTS, GEO, flux, Arctic

Level1 Algorithm for TANSO-FTS on GOSAT: Calibration and Correction of four years data

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The Greenhouse gases Observing SATellite (GOSAT) has observed carbon dioxide (CO2) and methane (CH4) globally from space for 4 years since Feb., 2009. The Thermal And Near infrared Sensor for carbon Observation Fourier-Transform Spectrometer (TANSO-FTS) and Cloud and Aerosol Imager (TANSO-CAI) provide global data every three days. Onboard and vicarious calibrations have been performed. The radiometric, geometric, spectroscopic and polarimetric characterizations for 4 years are presented. Then, we will show recent on-orbit instrument status such as pointing accuracy, interferogram quality, thermal stability, and micro vibration. Since launch, we have updated the algorithm for more than 10 times by using calibration data and analyzing on-orbit performance. We will present the version up history of the TANSO-FTS Level 1 data processing and correction algorithm. Pointing error correction for the TANSO-FTS target mode operation is also presented.

Keywords: GOSAT, TANSO-FTS, TANSO-CAI, Calibration

Vicarious Calibration at Railroad Valley: OCO-2 Readiness

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From 2009 to 2012, a combined JAXA and JPL team together with collaborators from Colorado State University (CSU) and NASA Ames, have conducted successful field vicarious calibration campaigns at Railroad Valley, NV, in support of in-flight calibration of the TANSO-FTS sensor aboard Ibuki. In June 2013, a team from JAXA, JPL, Ames and CSU will again conduct vicarious calibration activities for GOSAT which will provide a last unique opportunity for a change from an annual intensive campaign mode, into a more agile and frequent short campaign mode, in support and readiness for OCO-2. While beginning to modify the campaign style toward a slimmer, more agile campaign, we also include new measurements to address major sources of uncertainty, and to test potential predictive independent measurements. Bidirectional Reflectance (BRDF) data are a major source of uncertainty in the top-of-atmosphere radiance estimates and resulting degradation factors, and are suspected to change with changing soil moisture. We are in the process of setting up 4 permanent telescoping stands for fast BRDF measurement (PARABOLA). We will also install vertical soil moisture sensor profiles. With the already automated meteorological data and BRDF (PARABOLA, off-nadir ASD), these will potentially be a BRDF forecasting tool.

Keywords: GOSAT, OCO-2, carbon dioxide, vicarious calibration

New methods to measure photosynthesis from space:

Chlorophyll Fluorescence

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Our ability to close the Earth's carbon budget and predict feedbacks in a warming climate depends critically on knowing where, when and how carbon dioxide is exchanged between the land and atmosphere. Terrestrial gross primary production (GPP) constitutes the largest flux component in the global carbon budget, however significant uncertainties remain in GPP estimates and its response to environmental stress. We are able to observe globally from space a by-product of photosynthesis—chlorophyll fluorescence, which we retrieve using Fraunhofer lines in the 757 and 771nm region of high resolution spectra recorded by the Japanese GOSAT satellite. We argue from theory that fluorescence intensity should be correlated with GPP, and we show that global spaceborne observations of solar induced chlorophyll fluorescence exhibit a strong linear correlation with estimates of GPP derived from traditional remotely sensed vegetation indices using models and additional meteorological data. We suggest that remote sensing of chlorophyll fluorescence may provide a way to validate GPP simulations in carbon cycle models.

We will further discuss recent findings, including simulated fluorescence retrievals in cloudy atmospheres and latest comparisons with global GPP models as well as the June 2009-March 2013 time series based on the recent v150 GOSAT dataset.

Keywords: GOSAT, chlorophyll, fluorescence, GPP

The Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) FTS: Preliminary Results From 2012/2013 Ground-Based, Test Flights, and Science Operations

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The Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) is an aircraft-based NASA EV1 mission to study the carbon balance of the Alaskan Arctic ecosystem, with particular focus on carbon release from melting permafrost. Based in Fairbanks, AK, the CARVE aircraft covers the Alaskan interior, the Yukon River valley, and northern Alaska around Barrow and Dead Horse. CARVE observations cover the Arctic Spring/Summer/Fall seasons, with multiple flights per season. Science operations started in 05/2012 and are envisaged to continue until 2015. The CARVE suite of instruments includes flasks and *in situ* gas analyzers for CO_2, CH_4 and CO, a FLIR® IR camera for surface conditions, and a 3-band FTS for CO_2, CH_4, CO and interfering species, covering 4,200-4,900 cm^{-1}, 5,800-6,400 cm^{-1}, and 12,900-13,200 cm^{-1} with 0.2 cm^{-1} spectral resolution. The CARVE aircraft has completed the full 2012 campaign and is currently being prepared for the 2013 flights. We present preliminary results from FTS column observations of CO_2, CH_4, and CO, made from the ground, during test flights, and from science flights in Alaska during the 2012 and 2013 campaigns. The FTS has performed well during flight conditions. Outstanding challenges include the need for improved spectral and radiometric calibration, and compensation for low S/N spectra acquired under Alaskan conditions.

Keywords: Alaskan Arctic, carbon dioxide, methane, carbon monoxide, retrieval

An overview of ACOS Build 3.3 XCO_2 retrievals from GOSAT and first validation results

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The Atmospheric Carbon Observations from Space (ACOS) team has been processing GOSAT data since the summer of 2009, and is nearing the release of our sixth algorithm version, called Build 3.3. This new version has several improvements aimed at reducing biases that can result from over-fitting. Namely, we have a new treatment of systematic residuals, updated spectroscopy, and modifications to our state vector. These updates include a retrieval of chlorophyll fluorescence, which is expected to reduce or eliminate biases caused by ignoring this process. In new comparisons with TCCON, we find that Build 3.3 XCO2 has slightly reduced biases as compared to previous ACOS algorithm versions. We focus particular attention on the persistence of biases in Europe with respect to TCCON, which may connected with the unexpectedly large summertime drawdown inferred by recent top-down inversion studies which use GOSAT data to constrain carbon fluxes.

Keywords: GOSAT, carbon dioxide, retrieval, validation

Atmospheric CO_2 retrievals from GOSAT TANSO-FTS data and status on related French activities

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We have set up a processing chain for the retrieval of the column averaged CO_2 mixing ratio from TANSO-FTS data. This chain is including i) the download, selection, formatting and prescreening of NIES/JAXA hdf files, ii) a spectral calibration before the inversion step, iii) retrievals from O_2 and CO_2 spectral information (in bands B1 and B2, respectively) using the 4A-SWIR Radiative Transfer Model and the Optimal Estimation Method and iv) the post-screening of derived CO_2 products. A selection of about 10 000 spectra covering 16 months from April 2009 to August 2010 was selected in coincidence with 6 stations of the TCCON network and over the Solar-Village station in Saudi Arabia. Comparison is done against TCCON measurements and L2 products of NIES, Leicester University and Netherlands Institute for Space Research. This validation results are encouraging, showing a good consistency between the various CO_2 column estimates. Additional ongoing work within our RA project will be briefly discussed. The link with the French thematic data center Ether will be presented.

Keywords: GOSAT, carbon dioxide, retrieval, validation, inter-comparison

Column Retrievals of CO_2 and CH_4 from GOSAT

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The first dedicated greenhouse gas sensor GOSAT was launched in 2009 and we have now global GOSAT soundings of CO_2 and CH_4 columns for more than four years. Much progress has been achieved in instrument calibration, spectroscopy and retrieval algorithm development and retrievals of CO_2 and CH_4 approach now accuracies of around 0.3% when compared to ground-based validation sites, but some regions that lack validation sites such as deserts tend to show somewhat larger biases.

In this paper, we will present the results of CO_2 and CH_4 from GOSAT obtained with the new retrieval version of University of Leicester. Despite much progress in the retrieval methods, the quality of the column retrievals depends on data filtering and bias-correction methods and we will describe the applied methods. To characterize the retrieval results and the associated errors, we have carried out comparisons to ground-based column retrievals from the Total Carbon Column Observing Network (TCCON) and we have investigated the consistency of the retrieved columns with calculations from atmospheric transport models.

Keywords: carbon dioxide, methane, new instrumentation, validation

Seasonal carbon uptake as seen from an improved version of RemoTeC

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The “full physics” retrieval algorithm RemoTeC has been shown to deliver highly accurate carbon dioxide and methane dry air mole fractions (XCO_2 and XCH_4) from shortwave-infrared spectra collected by the Greenhouse Gases Observing Satellite (GOSAT). We report on recent developments of the algorithm including a scheme that corrects for residual bias by comparison of the retrieved XCO_2 and XCH_4 to ground-based measurements of the Total Carbon Column Observing Network (TCCON). We discuss improved understanding of radiative transfer in ocean-glint geometry and report on some progress in using short-cut methods for the retrieval of XCO_2.

We further highlight that our RemoTeC-GOSAT retrievals are able to deliver new insight into carbon cycle processes by comparing the XCO_2 seasonal cycle between the years 2009 and 2010. The seasonal differences are heavily affected by reduced carbon uptake in 2010 possibly caused by exceptional drought and fires in Eurasia.

Keywords: Seasonal carbon uptake, GOSAT, algorithm development

Carbon dioxide retrieval from IASI/Metop-A measurements and comparison with TANSO-FTS/GOSAT SWIR products

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We present the results of development and application of a dedicated software, based on the KLIMA inversion algorithm, optimally suited for CO_2 retrieval and integrated into the ESA grid-based operational environment G-POD to process IASI/MetOp-A Level-1 data and to perform a comparison with TANSO-FTS/GOSAT Level-2 data. Optimized versions of the KLIMA algorithm were investigated, to develop a non-operational retrieval code with capabilities that meet the requirements of comparison with TANSO-FTS and with adequate features for integration on the G-POD system. Using the KLIMA retrieval code on G-POD, we processed one week per month of a complete year of IASI measurements (March 1, 2010 - February 28, 2011). An extensive comparison of the retrieved CO_2 total columns was performed against operational Level-2 products from collocated TANSO-FTS observations and against the products of TCCON ground stations.

The results of KLIMA-IASI wide-band and multi-target analysis show good quality fits. Evidence of a negative bias of KLIMA-IASI XCO_2 values is found on average relative to other instruments, along with a good agreement of the observed geographical and seasonal variability with expectations.

In this presentation, we give an overview of current outcomes of our study and discuss key open issues and perspectives for future improvements.

Keywords: IASI/MetOp-A non-operational retrieval, TANSO-FTS/GOSAT operational products, cross-comparison

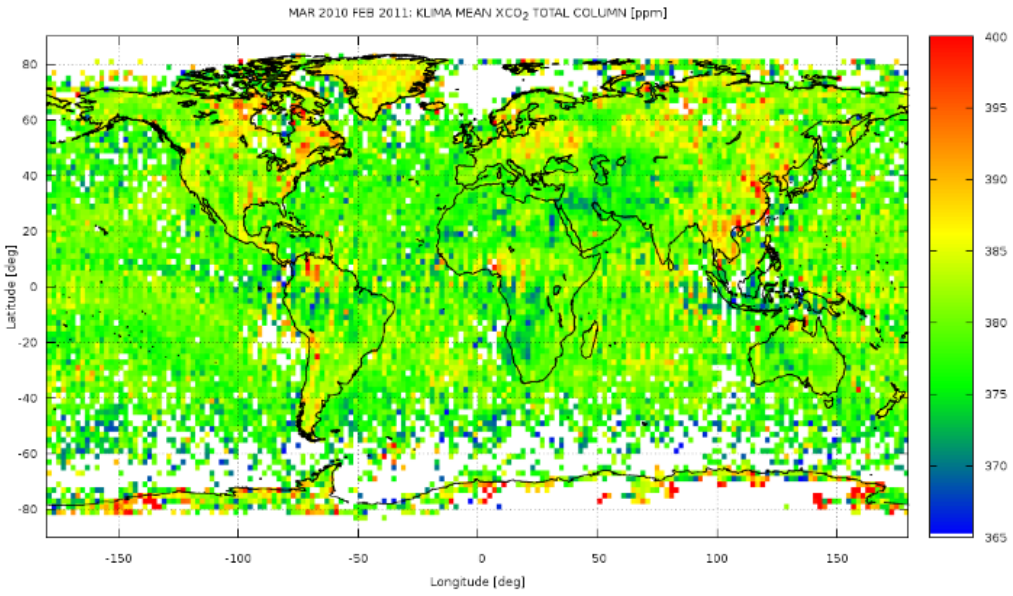

Figure 1

Global map of KLIMA-IASI XCO_2 column averaged in the full year (March 1, 2010 – February 28, 2011) over 2°x2° pixels

The Covariation of Northern Hemisphere Summertime CO_2 with Surface Temperature at Boreal Latitudes

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Over the past several years, significant interannual variability in the strength of the seasonal cycle drawdown in northern midlatitudes has been observed from measurements of CO_2 made by the Total Carbon Column Observing Network (TCCON) and the Greenhouse Gases Observing Satellite (GOSAT). This interannual variability in the seasonal cycle minimum correlates with changes in the summertime surface temperature in boreal latitudes. The CarbonTracker 2011 assimilation and GEOS-Chem simulations using the Simple Biosphere exchange Model (SiB) also show a correlation between summertime surface temperature and the seasonal cycle minima in CO_2, but with a smaller slope than that observed. The correlation found in the assimilation and model seems to be caused both by large-scale dynamical mixing and biospheric activity, in roughly equal proportion. The effects of emissions from fossil fuel combustion and fires appear to be small and uncorrelated with surface temperature.

Keywords: TCCON, GOSAT, carbon dioxide, biosphere

Approach for Clustering Spatio-Temporal Carbon Dioxide Data Using Satellite Observations

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Observations of atmospheric Carbon Dioxide (CO2) from satellite offer us new data sources to understand global carbon cycling. Data mining techniques, such as clustering, can be employed to uncover the CO2 distribution and cycling patterns, which will enable us to better understand and predict changes in the global carbon cycle. Cluster is one of the most major data mining methods for knowledge discovery in earth science data. Clustering of satellite-observed CO2 is the process of partitioning CO2 data sets into groups according to similarity of CO2 properties, and understanding how the physical properties of the CO2 are distributed in spatial domain. In this paper, a K-means based clustering approach, by considering the spatio-temporal trend and variability of CO2, is developed for satellite-observed CO2. The cluster results will be more reliable since the detrended CO2 data reflects the underline CO2 variability. The proposed approach is applied to the mainland China, as a case study, using two datasets: one is derived from observations of the Greenhouse Gases Observing Satellite (GOSAT) while another is the corresponding interpolated dataset using spatio-temporal geostatistical method. The advantages of our approach are identified by comparing with the results obtained by the conventional standard K-means approach.

Keywords: Clustering, GOSAT, CO2, K-means

N_2O and CH_4 Observation using Thermal Infrared Sounders AIRS, IASI and CrIS

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CH_4 and N_2O are two important Greenhouse gases (GHGs) after CO_2. This presentation will first give the validation to the AIRS-V6 CH_4 products that were just released in March, 2013, as well as the validation to the CH4 products from IASI generated on ***NOAA's* Comprehensive Large Array-data Stewardship *System*** (CLASS). As a new product, N_2O were recently retrieved from AIRS. It is found that the trend of N_2O from 2003 to 2012 can be well observed by AIRS while keeping a fixed first guess. Retrieval of N_2O from IASI will be put into operation in NOAA CLASS in September 2013. NOAA also plans to use the full spectrum CrIS data on NPP and JPSS to retrieve these GHGs. Some preliminary results from CrIS and its comparison with AIRS and IASI will be covered.

Keywords: N2O, CH4, AIRS/ IASI/ CrIS, retrieval, validation

Role of GOSAT total column CO_2 observations in the estimation of CO_2 surface fluxes

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Two unresolved questions surrounding the use of data from the Greenhouse gases Observing SATellite "IBUKI" (GOSAT) are (a) the extent to which the GOSAT XCO_2 observations can constrain global fine-scale flux estimates, and (b) the degree to which the dense but lower precision GOSAT data can provide additional information relative to the high precision but sparse observations from the *in situ* network. In this work, XCO_2 observations retrieved via the GOSAT-ACOS B3.3 algorithm, the Total Column Carbon Observing Network (TCCON), and CO_2 measurements from surface flask sites are assimilated using a geostatistical ensemble square root filter (GEnSRF) to constrain global surface fluxes at high spatiotemporal resolutions (spatial: 1° × 1.25°; temporal: daily). The value of the different observations is assessed via a diagnostic metric based on information theory, which within the GEnSRF framework allows for a quantification of observational influence on the posterior flux estimates. Results illustrate that the high-density satellite observations are useful in constraining ocean fluxes, where the surface network has limited coverage, but have a limited influence on the analysis over land relative to the ground-based network. This result is primarily attributed to the challenge associated with using current atmospheric transport models to accurately represent the link between variations in column-averaged CO_2 concentrations to the CO_2 surface fluxes.

Keywords: GOSAT, TCCON, carbon dioxide flux estimation, ensemble data assimilation, influence matrix

Modeling the column-integrated signal from a point-source: Progress and Problems.

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One motivation for the measurement of column-integrated CO2, especially at high resolution, is the ability to estimate point sources. We can test this in a limited way with ground-based measurements. In May 2012 we undertook a field trial near a power-station in South Australia. This talk presents our efforts to model this trial with high-resolution transport models.

Qualitative agreement between simulations and observations is relatively easy but quantitative emissions estimates more difficult. There is observational and modeling evidence for the influence of the nearby small town but this is more important for in-situ than column-integrated measurements. More importantly, simulations need to be filtered by wind direction before they can be used in the inversion. We explain the reasons for this with a simple two-component inversion calculation. Once we include this filtering the emissions estimate is close to the nominal emissions from the power-station during this period although the small sample size means uncertainties remain high.

Inverse modeling of the regional CO_2 fluxes with GOSAT XCO_2 observations

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We estimate surface CO2 fluxes using atmospheric transport model and GOSAT observations. The NIES-retrieved CO_2 column mixing ratio is used together with ground-based observations. The column averaged CO_2 mixing ratio (X_{CO2}) and column averaging kernel are provided by GOSAT Level 2 product v.2. Monthly mean CO2 fluxes for 64 regions are estimated together with a global mean offset between GOSAT data and Globalview. Net ecosystem exchange is predicted by the Vegetation Integrative SImulator for Trace gases (VISIT) terrestrial biosphere model optimized to match seasonal cycle of the atmospheric CO_2. Monthly ocean-atmosphere CO2 fluxes are produced with an ocean pCO_2 data assimilation system. Biomass burning fluxes are provided by the Global Fire Emissions Database (GFED). Fossil fuel CO_2 emissions are estimated with ODIAC inventory based in on nightlights observations and the a large point source database. We use fixed-lag Kalman smoother to infer monthly fluxes for 42 sub-continental terrestrial regions and 22 oceanic basins. When both GOSAT and ground-based data are used together the fluxes change compared to using only ground-based data in the tropical and other remote regions, for those regions flux uncertainties are reduced when compared to ground-based data only case. Analysis of the estimated flux deviations from prior suggest that additional constrains introduced by GOSAT observations reduces flux variance for the regions which are under-constrained when only ground-based data are used. Although the fluxes appear reasonable for many regions and seasons, more scientific results can be expected after improving the retrieval algorithms, data filtering and the inverse modeling method to reduce apparent estimated flux anomalies visible in some areas. In GOSAT Level 4 v.2, product we use aggregation of the GOSAT observations into monthly means over 5x5 degree grids. In the recently developed updates the model-observation misfit is estimated for each observation separately and transport simulation is enhanced by coupling with Lagrangian transport model Flexpart.

Keywords: GOSAT, carbon dioxide fluxes, inverse modeling

Inter-comparison of surface CO_2 fluxes estimated from latest GOSAT XCO_2 products using a single inverse modeling scheme

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Elucidating the distribution and temporal variability of surface CO_2 fluxes is an active research topic in the field of contemporary carbon cycle dynamics. The estimation of CO_2 fluxes in the past were carried out by utilizing CO_2 measurements collected in global networks of surface-based monitoring sites. Now, datasets of column-averaged CO_2 dry air mole fraction (X_{CO2}) retrieved from spectral soundings collected by GOSAT are available for complementing the surface-based CO_2 data. Currently, there exists five X_{CO2} retrieval algorithms developed by four research groups/institutes worldwide. As part of an ongoing effort in inter-comparing multiple GOSAT-based surface CO_2 flux estimates, we evaluated the influence of inter-product X_{CO2} differences on surface flux estimates. We did so by inferring monthly CO_2 fluxes in 64 sub-continental regions using a single inverse modeling scheme. The input to the modeling system are monthly-mean GLOBALVIEW CO2 values and each of the five independent X_{CO2} retrievals that are gridded to 5°×5° cells and averaged on a monthly time scale. We further simulated CO_2 concentrations in 3-D model space using the surface flux estimated. We herein report the degree of spread in the monthly flux estimates and the simulated CO_2 concentrations.

Keyword: surface CO_2 flux estimation, X_{CO2} retrievals

Quantifying Regional Sources and Sinks of Atmospheric CO_2 from GOSAT XCO_2 Data

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We have used **column**-averaged volume mixing ratios of carbon dioxide (XCO_2) from the Greenhouse Gases Observing Satellite (GOSAT), together with the 4-dimensional variational data assimilation system in the GEOS-Chem model, to quantify regional fluxes of atmospheric CO_2. In particular, we assess the sensitivity of the inferred regional flux estimates to residual biases in the GOSAT data. We employ three different bias correction schemes to filter the GOSAT data and examine their impact on the flux estimates. We find, for example, that the flux estimates for temperate North America and South America are strongly sensitive to our choice of filtering. As expected, we find that the uncertainty reduction on the flux estimates depends on the GOSAT observational coverage. For regions such as Europe, there is minimal uncertainty reduction on the monthly mean flux estimates in boreal winter as a result of limited observational coverage at high latitudes in winter. We also compare the fluxes inferred from the GOSAT data to those obtained from assimilation of surface data from the NOAA Earth System Research Laboratory Global Monitoring Division and Environment Canada to assess the complementarity of the satellite and surface CO_2 data in the context of the assimilation.

Keywords: GOSAT, carbon dioxide, assimilation, flux inversion

Validation of GOSAT CO_2 flux product over the grassland

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Greenhouse Gases Observing Satellite (GOSAT) is the first satellite in orbit dedicated to measure the concentration of carbon dioxide and methane of atmosphere. The primary purpose of the GOSAT project is to make a more accurate estimate of the flux of the greenhouse gases on a subcontinental basis. GOSAT has the advantages of continuous observations and global coverage, which will overcome the limitation of sparse ground-based monitoring stations. The GOSAT satellite has released a direct estimation of CO_2 (L4A global CO_2 flux) flux maps at monthly interval and 1º spatial resolution at the global scale. However, the GOSAT flux map has its issues on coarse spatial and temporal resolutions and the uncertainties derived from the atmospheric transport model. Therefore, it is important for users to understand the data quality for carbon flux modeling and global change studies. In this study, the GOSAT L4A global CO2 flux data was validated with the flux tower measurement and compared with estimation from our data-driven piecewise regression model (PWR) model over the North American and northern China grasslands. Results showed 1) Although the magnitude of the difference between GOSAT and tower-measured fluxes varied at sites, the GOSAT captured the seasonal variations of fluxes well at several sites. However, the seasonal variations are opposite between GOSAT and tower-measured fluxes at several sites. The discrepancy at those sites may be caused by the unmatched spatial scales due to the very coarse resolution of GOSAT data compared to the site-level flux tower data. 2) The monthly variations of PWR-estimated NPE matched GOSAT NEP well although the magnitudes of the NEP values appeared some differences. The correlation between PWR-estimated NPE and GOSAT is R^2=0.72. 3) Based on GOSAT L4A data from June, 2009 to May, 2010, the carbon sink capabilities and emission over China are evaluated at the annual and monthly time steps.

Research Topic: Validation, Data application

Vegetation Fires and Air Pollution in South Asia – Analysis from Multi-Satellite Datasets

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Vegetation fires are an important source of air pollution in several regions of the world including Asia. An important question with respect to satellite retrievals of air pollutants is "how well do they capture temporal and spatial variations and how well do they relate to episodic events such as fires?" We addressed this question using multi-satellite data, i.e., MOPITT (CO), GOSAT (CO_2), OMI aerosol index, MODIS aerosol optical depth (AOD) as well as small mode aerosol fraction (SMAF). Results from temporal analysis (2003-2012) of fires in Asia suggested 22% of all fires occurring in Myanmar, followed by India (20.91%), Indonesia (18.31%), Thailand 9.42%), etc. Fire frequencies were highest in northeast India and Southeast Asia countries. Further, we observed significant spatial variation and seasonality in fires in Southeast Asia. AOD followed a similar trend as that of fires, however, small mode aerosol fraction showed some discrepancies. OMI-AI well correlated with fire seasonality. Also, results showed that areas with high vegetation fires were also areas of high CO, CO_2 emissions, with highest spatial correlation during the month of March. GOSAT data could explain 39% of CO_2 variations from vegetation fires. Among the fire counts and fire radiative power (FRP), the correlations varied for individual months, however, both showed significant ($P<0.001$) positive correlations. The study captures the influence of vegetation fires on air pollution in Asia using multi-satellite datasets.

Keywords: vegetation fires, tropospheric satellites, air pollution

Estimating the 2010 flux CO_2 anomaly over Eurasia from a source-sink inversion of GOSAT XCO_2: Is there a robust feature?

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Assimilating GOSAT total column CO_2 (XCO_2) measurements in addition to surface measurements in a source-sink inversion offers the tempting possibility of imposing constraints on CO_2 surface fluxes globally. It is, however, difficult to deduce whether certain features in the estimated fluxes are "real" or artifacts of biases in satellite retrievals. In this talk, we briefly present global flux estimates obtained from assimilating GOSAT XCO_2, before focusing on boreal Eurasia, an ecologically active region poorly sampled by the surface network. We look at the inter-annual variability (IAV) of XCO_2 and estimated fluxes over Eurasia, which is a more robust quantity than the fluxes themselves. We show that GOSAT XCO_2 over Eurasia points to a difference in the summer uptake between 2009 and 2010, which is only partly captured by the existing surface measurement network. Based on the time of onset and magnitude of this IAV, we suggest that this IAV was produced by the 2010 Russian fires, and the 2010 heat wave which affected the terrestrial biosphere. We claim that this IAV in the estimated fluxes is a "real" feature, not affected by systematic biases in XCO_2 which might plague standard XCO_2-based emission estimates.

Keywords: Inverse modeling, GOSAT XCO_2, inter-annual variability

Large point source emissions signatures seem from Space

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Fossil fuel CO_2 emissions is a major input to the global carbon cycle over decadal time scales and need to be curbed in order to mitigate global climate change. Changes in those emissions need to be monitored, we however lack an objective method to do so directly and/or verify the reported emissions. Future carbon-observing space missions are thus expected to provide an independent tool for directly measuring these emissions. Since 2009, we have implemented dedicated satellite observations specifically made over intense large point sources (LPS) such as large power plants and megacities to detect emissions' signature, using the Japanese Greenhouse Gases Observing SATelllite (GOSAT). We have analyzed five GOSAT X_{CO2} retrievals available from four research groups (NIES-L2, NIES-PPDF, ACOS, RemoTeC and UoL FP). Although we have obtained fewer retrieved soundings relative to our original requests likely due to geophysical difficulties in the retrievals, we have found statistically significant enhancements at some LPS sites where weather conditions were ideal for viewing. We have also implemented simulations of enhanced X_{CO2} using the Global Eulerian-Lagrangian Coupled atmospheric transport model (GELCA) and the high-resolution fossil fuel emissions dataset (Odiac).

Keywords: GOSAT, carbon dioxide, fossil fuel emissions, target mode observation, power plant

Estimation of CO_2 emission strength from a mega-sized city using satellite and in situ observation data

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The greenhouse gas observing satellite (GOSAT) has functioned normally for more than four years since its launch on 23 January 2009. Although its main purpose is the measurement of greenhouse gases globally to reduce the estimation error of source/sink strength in a sub-continental size region, it can measure gas concentrations at multiple targets on a regional scale during one orbital over-flight. We have initiated and conducted special observations to monitor CO_2 concentrations at sufficiently numerous observation sites and thereby cover all regions of a mega-sized city. The main sensor of the satellite, the “thermal and near infrared sensor for carbon observation Fourier transform spectrometer (TANSO-FTS)”, has been operated in a “specific operation mode” to measure CO_2 concentrations at 4 × 4 (totally 16) mesh points over the Kanto Plain, the center of which is Tokyo. This specific observation covers about 100 km × 100 km of the plain. During recent two years, more than 200 XCO_2 data have been collected under clear sky conditions. However, some of them, particularly over the urban area, show some low biases, and we are now investigating their causes. These satellite data are used as inputs as well as ground-based measurements operated by national and local governmental institutes, CO_2 sonde, and aircraft observations (CONTRAIL) into the inverse analysis of emission/sink strength of CO_2. The AIST meso-scale transport model (AIST-MM), whose highest spatial resolution is 1 km is used for the inverse analysis. Boundary conditions in a large area outside the regional target are provided by a general circulation model (GCM) based transport model (NICAM-TM). The system detected a signal of reduction of CO_2 emission from some industrial districts just after the Tohoku-Pacific Ocean Earthquake.

Keywords: GOSAT, carbon dioxide, Inverse analysis, CONTRAIL, CO_2 sonde, Mega-sized city

Diagnose of GHG Emission Over Indonesian Area Using GOSAT (Greenhouse Gases Observing Satellite) Data

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The Greenhouses Gases Observation Satellite (GOSAT) launched on January 23, 2009 to monitor the dynamics of greenhouse gases (GHG) in the earth's surface. GOSAT spatially measures carbon flux (including CH_4 and aerosols) in the regional to continental level and temporal scales from synoptic to interannual. This can be exploited to gather new knowledge about the global distribution and temporal variation of greenhouse gases will also be able to know at the same time the global carbon cycle and its influence on climate. The GOSAT can also potential be used to predict future climate change and its impact through developing a new methodology for the measurement of greenhouse gases. This study aimed to diagnose and monitor GHG emission over Indonesian area by coupling GOSAT data with relevant data (hot spot and meteorological data). Based on the initial analysis, it represents that the trend increased for both CO_2 and CH_4 concentration occured since 2009 until June 2012 over Indonesian area. Even if the trend after June 2011 represents the slight slump, yet the general trends indicate the increase form. Based on the analysis as well it depicts that the occurrence of hot spot (forest fire) has correlation with the raising trend of CO_2 and CH_4. In general phenomena and based the historical data during this time, the hot spot usually achieve the peak condition in dry season. The field condition during that time implies the direct or indirect correlation with distribution concentration of CO_2 and CH_4 during the July (2009, 2010 and 2011). This condition is not so much severe during January (2009, 2010 and 2011), where the rain fall was still high (rainy season). For the near future analysis, the uncertainty of the actual source of emission need more investigation and prove based by coupling with historical data of wind, as emission is a mix concentration (value) that come from some sources.

Patterns of CO_2 Sensitivity to CO from Space and their Implications for Carbon Monitoring

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Tracking anthropogenic emissions of CO_2 to the atmosphere remains to be a challenge. Here, we explore the added value of using space-based observations of CO to complement existing satellite observing systems for CO_2 in monitoring carbon emissions. In particular, we use retrievals of column CO from NASA/Terra MOPITT instrument, in conjunction with ACOSB2.9 retrievals of CO_2, from the GOSAT/TANSO instrument, to explore the feasibility of extracting complementary information about combustion-related processes and CO_2 transport over megacities. To enhance the signature of anthropogenic emissions in the lower troposphere, we use the multi-spectral retrievals (TIR/NIR) of CO from MOPITTv5, in combination with its current thermal-infrared (TIR) retrievals. We conduct a suite of 'targeted' regression analyses between observed enhancements of CO_2 and CO abundance. These were then validated through comparison with collocated column CO_2 and CO retrievals from TCCON surface stations. We find a clear trend in CO_2-CO sensitivities that correspond well with the developed/developing status of urban regions. These results agree (within 20%) with estimates from previous studies and EDGARv4.2 emission inventory. Future directions will include adding information from NO_2 retrievals and validating against field campaigns of air quality leading towards multi-species inverse modeling of combustion-related surface fluxes of greenhouse gases.

Keywords: CO_2, CO, Megacities, Sensitivity Analysis, Urban Enhancements

Characterization of biomass burning from combined analysis using SCIAMACHY, GOSAT and MOPITT

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Biomass burning emits many trace gases including CO, CO_2 and CH_4. Emissions of those trace species from the various types of biomass burning have been studied in the field measurements extensively. However, the large uncertainty is still a big issue to characterize the fire types and their impacts on the atmosphere. Satellite measurements of CO, CO_2 and CH_4 in the burning plumes are helpful to characterize the fires. If the concentrations of those species are not determined independently, the ratios such as CO/CO_2, CH_4/CO_2 in the plumes from fires can give us important information on the combustion characteristics of the fires, as suggested by many emission studies. The CH_4 retrievals introducing CO_2 as "proxy" for surface pressure gives us the CH_4/CO_2 ratio, which is directly obtained from spectral data observed by satellite and is a useful by-product to characterize combustion completeness of various fire types. Recently new version (V5) of the MOPITT data was released, which includes both NIR and TIR information. We show the results of combined analysis of the datasets from SCIAMACHY Version 5.5 (by C. Frankenberg), GOSAT/RemoTeC-proxy (by A. Butz) and MOPITT Version 5, and discuss potential of satellite sensors to characterize biomass burning.

Keywords: GOSAT, SCIAMACHY, MOPITT, biomass burning
**This study was supported by the Green Network of Excellence (GRENE-ei) of the MEXT.*

Interpreting Variations in Terrestrial Carbon Exchange in Tropical Regions Using GOSAT XCO_2 and Fluorescence

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Amazon forests exert a major influence on the global carbon cycle but quantifying the impact is complicated by diverse landscapes and sparse data. We use measurements of XCO_2 and solar induced chlorophyll fluorescence (SIF) from GOSAT to examine terrestrial carbon exchange throughout tropical South America. SIF, which reflects gross primary production (GPP), is used to disentangle the photosynthetic component of land-atmosphere carbon exchange. We find the combination of XCO2 and SIF reveals regional and seasonal differences in biological carbon exchange across southern Amazonia. This is possible because strong vertical mixing is tightly coupled to underlying surface processes such that changes in net carbon exchange are reflected in the column. We conclude that GOSAT provides critical measurements of carbon exchange in drier regions of southern Amazonia but more samples are needed to examine moist tropical forests farther north.

Satellite bias estimation by independent inverse analysis

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Recently, a number of satellite observation data have become available for use in carbon cycle analysis (GOSAT, AIRS and so on), and more satellite instruments (OCO-2, Carbonsat, Tansat and so on) are planned for launch in the next few years. The merits of satellite data in carbon cycle analysis include their large spatial coverage and relatively large space representativeness comparing with in-situ observations. However, there are non-trivial points that need to be reconsidered in satellite data. An important issue is bias, which may change with time and space. Many efforts have been made to estimate the bias, but most previous attempts used only a limited number of observations and did not consider spatial and temporal variations of the bias. In this research, we estimate satellite data bias from an independent analysis of CO2 concentrations (JMA CO2 distributions (Maki et al., 2010)) which provides global coverage on a monthly basis. The accuracy of the CO2 concentrations is almost 1.0 ppm in the southern hemisphere and free troposphere. The annual global mean bias of GOSAT SWIR Level 2 (Ver. 2.X) relative to the JMA CO2 analysis is approximately -1.4 ppm and shows some seasonal and latitudinal variations. Our estimates of annual-mean bias are consistent with previous studies.

Estimate of anthropogenic carbon fluxes from high spatial resolution CO_2 observations: Error estimates

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The Sentinel-5 instrument is dedicated to the measurement of atmospheric composition and will be launched onboard the MetOp satellite in 2020. CarbonSat was selected by ESA as a candidate for the 8 Earth Explorer Opportunity (EE8). CarbonSat shall have a spatial resolution of 2 km with a swath of 200-500 km. The spatial resolution of S-5 is not as high, but the instrument offers a much larger swath, ensuring near global daily coverage.

The imaging capabilities of both instruments make it possible to identify concentration plumes downwind of large emission sources such as cities or fossil-fuel power plants. The concentration gradient is directly related to the emission intensity so that the source intensity may be estimated through inverse transport modelling. There are however several source of uncertainties that need to be evaluated:

- Atmospheric transport and in particular the wind speed
- Measurement error and biases
- Inhomogeneous spatial and temporal distribution of the sources
- Impact of sources and sinks outside of the observation domain.
- Vertical distribution of the concentration plume

As part of an ESA funded study, LOGOFLUX, several tools have been developed to invert emission factors based on the column concentration measurements. A simple tool is a plume shape model that requires limited information about the atmospheric transport. Another type of tool uses a full description of the atmospheric transport and permits the estimation of the spatial and temporal structure of the source. These tools have been applied on simulated observations of the Paris area, as well as an hypothetical power plant.

The presentation will quantify these various sources of errors and provide an overall estimate of the CarbonSat and Sentinel-5 capabilities to monitor the anthropogenic sources of CO_2.

Keywords: CarbonSat, Sentinel-5, carbon dioxide, emissions

MACC-II analysis of tropospheric CH_4

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As part of the pre-operational Monitoring of Atmospheric Composition and Climate -Interim Implementation- (MACC-II) project, global atmospheric greenhouse gas concentrations are forecasted and analysed using the infrastructure of the ECMWF Integrated Forecasting System (IFS). We will present the analysed column-averaged dry-air mole fraction of methane (XCH4) constrained by the assimilation of satellite measurements.

The assimilated data are retrievals from the SCIAMACHY, TANSO and IASI instruments respectively onboard ENVISAT, GOSAT and MetOp-A. SCIAMACHY and TANSO retrievals are more sensitive to the lower troposphere while IASI retrievals are more sensitive to the mid-troposphere. SCIAMACHY measurements have a large global coverage, while TANSO measurements are retrieved mainly over land and IASI measurements are currently retrieved only in a tropical band between 30ºS and 30ºN. We will present how the differences between the instruments impact the analysis of tropospheric CH4.

As communications with ENVISAT were lost in April 2012, SCIAMACHY retrievals cannot be used any more to constrain the analysis of the tropospheric CH4. We will show that the combination of TANSO and IASI allows to compensate for the loss of SCIAMACHY, producing analyses with low biases compared to independent measurements.

Keywords: methane, data assimilation, TANSO, IASI, SCIAMACHY

Estimating regional methane surface fluxes using GOSAT XCH_4 observations

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We infer regional monthly surface flux estimates for methane (CH4) from proxy dry-air column-averaged mole fractions of CH4 from the Greenhouse gases Observing SATellite (GOSAT) using an ensemble Kalman Filter combined with the GEOS-Chem chemistry transport model. We compare these flux estimates with estimates inferred from in situ surface mole fraction measurements and from combining in situ and satellite measurements in order to quantify the added value of satellite data above the conventional surface measurement network. We report global and regional flux estimates inferred from satellite and/or in situ measurements. We evaluate the posterior fluxes by comparing them against independent surface mole fraction, column, and aircraft measurements using the GEOS-Chem model as an intermediary. We also explore the information provided by combining XCH4 and XCO2.

Keywords: methane, fluxes, assimilation, GOSAT

On the consistency between global and regional methane emissions inferred from SCIAMACHY, TANSO-FTS, IASI and surface measurements

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Satellite retrievals of methane weighted atmospheric columns are studied within a Bayesian inversion system to infer the global and regional methane emissions and sinks. 19-month inversions from June 2009 to December 2010 are independently computed from three different space-borne observing systems under various hypotheses for prior-flux and observation errors. Posterior methane emissions are inter-compared and evaluated with surface mole fraction measurements, via a chemistry-transport model. Sensitivity tests show that refining the assigned error statistics has a larger impact on the quality of the inverted fluxes than correcting for residual airmass-factor-dependent biases in the satellite retrievals. Improved configurations using TANSO-FTS, SCIAMACHY, IASI and surface measurements induce posterior methane global budgets of respectively, 568±17 Tg/yr, 603±28 Tg/yr, 524±16 Tg/yr and 538±20 Tg/yr over the one-year period August 2009-July 2010. This consistency between some of these satellite retrievals and surface measurements is promising for future improvement of CH4 emission estimates by inversions.

Keywords: GOSAT, methane, inversion, statistics

Seasonality in Fossil Fuel Industrial Emissions based on Surface and Satellite Transcontinental Data

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Data from a transcontinental surface methane, CH_4, survey from Florida to California were analyzed to improve understanding of some natural and anthropogenic CH_4 sources. Very high concentrations were found (>30 ppm) in areas of active fossil fuel production in central California. Repeat survey here showed the importance of boundary layer height with enhancements decreased by more than an order of magnitude during daytime compared to nighttime.

Data were used to validate satellite (GOSAT and SCIAMACHY)-derived large-scale CH_4 trends across the southern portion of the US. Comparison of CH_4 inventory predictions with satellite data suggests that fossil CH_4 budgets are significantly underestimating contributions in some areas and seasons. Further investigation revealed that anthropogenic emissions associated with fossil fuel activities exhibit seasonal variations, which should be accounted for in future inventory models.

Keywords: Methane, GOSAT, SCIAMACHY, Seasonal, Fossil Fuel Industry Fugitive Emissions

Evaluation of radiometric degradation of GOSAT TANSO-FTS via analysis of derived surface albedo

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Recent work [Yoshida, AMT, 2012] used GOSAT monthly solar observations to confirm suspected degradation of the radiometric sensitivity of the TANSO-FTS instrument in the near infrared. In this work, we leverage the relationship between the radiant intensity of reflected short-wave sunlight and the solar flux, geometry and surface albedo to study this time-dependence, with the goal of finding consistent results with the solar-based method. This is done in two ways. We briefly discuss the results of the 2009-2012 Railroad Valley vicarious calibration campaigns and show their broad consistency with the solar diffuser measurements. Second, we investigate the hypothesis that a four year time series of surface albedos, inverted from L1b radiances and subsetted to small regions with reasonably uniform surfaces, allows characterization of drifts in the instrument sensitivity. To first order, the radiant intensity relationship corrects for the seasonal cycle, due to both BRDF effects and changes in the underlying surface. Comparison of all-sky versus cloud-screened data sets is used to determine the sensitivity to the presence of clouds and aerosols. Variance in the albedo time series is an indicator of the uncertainty. This technique could also be applied to future missions, in particular that of OCO-2.

Keywords: GOSAT, calibration

Extension of the targets for the GOSAT SWIR XCO_2 and XCH_4 retrievals

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The column-averaged dry air mole fractions of carbon dioxide and methane (XCO_2 and XCH_4) have been retrieved globally from the Short-Wavelength InfraRed (SWIR) spectral data observed with the Thermal And Near-infrared Sensor for carbon Observation Fourier Transform Spectrometer (TANSO-FTS) onboard Greenhouse gases Observing SATellite (GOSAT). The retrieval results have been released as the GOSAT TANSO-FTS SWIR L2 product. Until the SWIR L2 V02.xx retrievals, the strict cloud screening is applied to select cloud-free scenes and XCO_2 and XCH_4 are retrieved under the assumption of "no-cloud" condition. Also, we apply relatively strict post-screening criteria to exclude the potential outlier. As a next step, we plan to extend the retrieval target by weakening the screening criteria and adding new auxiliary parameters into the state vector. For example, the 2-micron cirrus screening is switched off, and optical depth, effective diameter, and cloud-top pressure of cirrus are included in the state vector for cirrus cases. Rough comparison of retrieved XCO_2 for cirrus/no-cirrus cases shows similar characteristics. Detail analysis including validation with the TCCON data will be shown in the presentation.

Keywords: GOSAT, carbon dioxide, methane, cirrus

Retrievals of atmospheric CO_2, CH_4 and optical path modifications from the GOSAT observations

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We present retrievals of the column-averaged dry air mole fraction of atmospheric carbon dioxide (X_{CO2}) and methane (X_{CH4}), which were derived from the radiance spectra measured by Greenhouse gases Observing SATellite (GOSAT).

We have applied new version of the Photon path-length Probability Density Function (PPDF) -based algorithm to estimate X_{CO2} and PPDF parameters. These parameters serve to allow for optical path modification due to atmospheric light scattering and they are retrieved simultaneously with CO_2 concentration.

Three dimensional PPDF model was applied for the atmospheric light scattering correction. Main retrieved PPDF parameters include aerosol layer altitude, layer relative reflectivity, and scaled first moment of the PPDF describing multiple reflection and scattering of light within the layer.

For the methane abundance retrieved from 1.67-μm absorption band we applied optical path correction based on PPDF parameters from 1.6-μm CO_2 absorption band. Both carbon dioxide and methane GOSAT retrievals were validated using ground-based measurements provided by the Total Carbon Column Observing Network.

We analyzed X_{CO2} and X_{CH4} GOSAT-PPDF retrievals for 26 months of GOSAT operation from June 2009. We estimated temporal and spatial trends and compared them with modeled data as well as with other GOSAT retrieval algorithms.

Keywords: GOSAT, carbon dioxide, methane, retrieval

An Algorithm for Greenhouse Gas Retrievals Using Polarization Information Measured by GOSAT TANSO-FTS

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We present an algorithm for retrieving column-averaged dry air mole fractions of carbon dioxide (XCO_2) and methane (XCH_4) from polarization spectra measured by GOSAT TANSO-FTS in the shortwave infrared (SWIR). TANSO-FTS acquires two linear polarization spectra, primary (P) and secondary (S), in SWIR. So far, the NIES operational algorithm for retrieving XCO_2 and XCH_4 is designed not to use P and S polarizations directly, but to use total radiation intensity as an input, which is re-constructed from P and S polarizations by an approximate polarization correction algorithm. One of the advantages of using the polarization correction algorithm is the higher SNR spectra achieved by adding P and S polarizations to get total radiation intensity. In addition, scalar radiative transfer calculations are much simpler and faster than vector radiative transfer calculations. On the other hand, the main disadvantage of the polarization correction is that polarization information is lost, which, in principle, might be useful to correct interference effects of clouds and aerosols on retrievals of XCO_2 and XCH_4. In this paper, our vector version of the retrieval algorithm, as well as its scalar counterpart, is described. A key feature of the vector retrieval algorithm is implementation of the bidirectional polarization distribution function for land surface. We will discuss how retrievals of XCO_2 and XCH_4 are improved by aerosol correction algorithms using polarization information.

Keywords: GOSAT, carbon dioxide, methane, retrieval

Validation of GOSAT SWIR XCO_2 and XCH_4 using TCCON data: Parameter dependency of GOSAT biases and the bias correction

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Column-averaged volume mixing ratios of carbon dioxide and methane (XCO_2 and XCH_4) retrieved from Greenhouse gases Observing SATellite (GOSAT) Short-Wavelength InfraRed (SWIR) observations (hereafter GOSAT data) were validated with data obtained by the Total Carbon Column Observing Network (TCCON). Although Ver. 02.xx of GOSAT data shows much smaller biases than Ver. 01.xx, time series of the differences between GOSAT and TCCON data (i.e., biases of GOSAT data) exhibit seasonal variations and annual trends. These results imply that GOSAT biases could be attributed to several time-dependent parameters. Therefore, we conducted correlation analysis between GOSAT biases and the simultaneously retrieved auxiliary parameters, and corrected GOSAT data by multiple linear regression on four parameters (the difference between the retrieved and a priori surface pressures, the retrieved aerosol optical depth, airmass, and surface albedo) which are correlated with the GOSAT biases, to cancel out correlation of them. We found higher correlations between the corrected GOSAT and TCCON data. Averages±standard deviations of uncorrected GOSAT biases over land regions were -1.46±2.24 ppm for XCO_2 and -5.3±14.4 ppb for XCH_4, whereas those for the corrected GOSAT data became as small as -0.01±1.95 ppm for XCO_2 and 0.0±13.4 ppb for XCH_4.

Keywords: GOSAT, XCO_2 and XCH_4, validation, TCCON, bias correction

Series of measurements from new possible validation site at Kourovka

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The Kourovka observation site (Ural Atmospheric Fourier Station, 57.038N, 59.545E) is equipped with Fourier interferometer Bruker Optics IFS125M with solar tracker, Picarro L2130-i water vapor isotopic analyzer, and Gill Instruments MetPak-II meteorological station. Altogether with solar irradiance spectra the following parameters are measured at surface continuously: atmospheric pressure, air temperature, relative humidity, speed and direction of wind, absolute concentration of water vapor (ppm), values of δHDO and $\delta H_2{}^{18}O$ (expressed in ‰). Approximately 500 solar spectra had been recorded since summer of 2012. Series of retrieved columnar values of CO_2, CH_4, CO, $H_2{}^{16}O$, $HD^{16}O$, $H_2{}^{18}O$ are represented. Time series of H_2O, δHDO and $\delta H_2{}^{18}O$ in-situ measurements altogether with temperature measurements are also represented. Correlations between FTIR columnar values and in-situ measurements are discussed. Precipitation sampling for further water isotopic analysis is also organized.

Keywords: validation site, FTIR ground-based measurements.

Comparison of CO_2 column concentrations calculated from GOSAT SWIR with balloon-borne CO_2 instrument measurements

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The Greenhouse gases observing satellite (GOSAT), launched on January 23, 2009, has monitored atmospheric CO_2 and CH_4 globally from space. The Thermal And Near infrared Sensor for carbon Observation-Fourier Transform Spectrometer (TANSO-FTS) onboard GOSAT has two detectable regions; Short-Wavelength Infrared (SWIR) and Thermal Infrared (TIR). The global distribution of column-averaged dry air mole fractions of CO_2 (XCO_2) and CO_2 profile, called as GOSAT products, are retrieved from SWIR and TIR spectra. It is essential to evaluate the uncertainty of GOSAT products for detail understanding of global distribution and surface flux of CO_2.

In this study, we compared the XCO_2 derived from GOSAT with those calculated from originally developed balloon-borne CO_2 instrument (CO_2 sonde), which can measure CO_2 vertical profile up to the altitude of ~10 km. The CO_2 sensors are based on the non-dispersed infrared absorption spectroscopic technique (NDIR) at the wavelength of 4.0μm as a background and 4.3 μm for CO_2 absorption. We used four vertical profiles of CO_2 obtained using the CO2 sonde at three sites synchronized with GOSAT overpass for comparison; January 7, 2011 at Ichihara, January 31, 2011 at Moriya, June 30, 2012 at Moriya, and July 30, 2012 at Shirako, Japan.

Key words: balloon-borne measurement, carbon dioxide, GOSAT, validation

Comparison of GOSAT XCH_4 and airborne measurements over Siberia

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The Greenhouse Gases Observing Satellite (GOSAT) was launched on 23 January 2009. In order to apply the GOSAT products to estimate CH_4 budget by inverse analysis, we need to confirm the quality of the GOSAT CH_4 data carefully. The result of validation of GOSAT XCH_4 (version 02.xx) by comparing them with TCCON XCH_4 is reported in "Summary of NIES the GOSAT Level 2 Data Product Validation Activity" as in Morino et al., [ACP,2011]; GOSAT XCH_4 is biased low by 7.0 ± 12.0 ppb (0.4 ± 0.7%). However, all TCCON sites are located in background regions, and validation of GOSAT data over the source regions is insufficient. Under the NIES program, airborne measurements have been carried out in Surgut and Novosibirsk, Siberia, since 1993 [Umezawa et al., GBC, 2012]. We apply the aircraft measurements over Siberia to assess the quality of the GOSAT XCH_4 dataset obtained from SWIR band. Conversion of the CH_4 profiles observed by aircraft into XCH_4 includes some uncertainties such as temperature profiles and CH_4 distribution in the stratosphere. In this presentation we report the detailed result of sensitivity analysis for those uncertainties.

Research Topic: Application

Acknowledgement: We thank to Andrea Butz and all RemoTec Team members, and all N2J members in JAXA and NICT for their efforts to process the new CH_4 dataset. This study was supported by the Environmental Research and Technology Development Fund (A-1202) of the MOE.

Impact of aerosols and cirrus clouds on the GOSAT-observed CO_2 and CH_4 inferred from ground-based lidar, skyradiometer and FTS data at prioritized observation sites

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We study the impact of aerosols and cirrus on the Greenhouse gases Observing SATellite (GOSAT) products of the column-averaged dry-air mole fraction of carbon dioxide (XCO_2) and methane (XCH_4) (Ver. 02.xx) using ground-based lidar, skyradiometer, and Fourier Transform Spectrometer (FTS) data at prioritized observation sites of Tsukuba (36.1°N, 140.1°E), Moshiri (44.4°N, 142.3°E), Saga (33.2°N, 130.3°E) and Lauder (45.0°S, 169.7°E). The main findings are as follows:

1) The screening of the GOSAT products by scattering in 2 micron band has eliminated most of the data points when cirrus clouds were detected with the lidar. However, it eliminated some data points showing good agreement with ground-based FTS data when thin cirrus clouds were present, suggesting that number of GOSAT data could be increased by a retrieval algorithm taking into account thin cirrus clouds.

2) A large difference was found between GOSAT and ground-based FTS data when dense aerosol layer was present in the atmospheric boundary layer over Saga on May 29, 2012.

3) The stratospheric aerosol increase after 2008 by volcanic eruptions with a Volcanic Explosivity Index (VEI) of 4 has non-negligible impact on the GOSAT products.

Further validation is necessary to improve the quality of GOSAT retrievals.

Keywords: GOSAT, validation, ground-based FTS, lidar, skyradiometer

Aerosol information content analysis of multi-angle high spectral resolution measurements and its benefit for high accuracy greenhouse gas retrievals

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New generations of space-borne spectrometers for the retrieval of atmospheric abundances of greenhouse gases require unprecedented accuracies as atmospheric variability of long-lived gases is very low. These instruments, such as GOSAT and OCO-2, typically use a high spectral resolution oxygen channel (O2 A-band) in addition to CO2 and CH4 channels to discriminate changes in the photon path-length distribution from actual trace gas amount changes. Inaccurate knowledge of the photon path-length distribution, determined by scatterers in the atmosphere, is the prime source of systematic biases in the retrieval. In this paper, we investigate the combined aerosol and greenhouse gas retrieval using multiple satellite viewing angles simultaneously. We find that this method, hitherto only applied in multi-angle imagery such as from POLDER or MISR, greatly enhances the ability to retrieve aerosol properties by 2–3 degrees of freedom. We find that the improved capability to retrieve aerosol parameters significantly reduces interference errors introduced into retrieved CO2 and CH4 total column averages. Instead of focussing solely on improvements in spectral and spatial resolution, signal-to-noise ratios or sampling frequency, multiple angles reduce uncertainty in space based greenhouse gas retrievals more effectively and provide a new potential for dedicated aerosols retrievals.

Keywords: GOSAT, OCO-2, multi-angle, aerosols, CO_2

Lidar observation of the 2011 Puyehue volcanic aerosols at Lauder, New Zealand

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On June 4, 2011, the Puyehue-Cordon Caulle volcanic complex (40.6S, 72.1W) in Chile erupted violently and injected volcanic aerosols into the atmosphere. For the safety of civil aviation, continuous lidar observations were made at Lauder, New Zealand (45.0S, 169.7E), during 11 June through 6 July 2011. To study the influence of the volcanic aerosols on the Greenhouse gases Observing SATellite (GOSAT) products, we analyzed lidar data and derived the backscatter ratio and depolarization ratio profiles at a wavelength of 532 nm.

The Puyehue volcanic aerosols had large depolarization ratios (about 20-35%) around 10-15 km. Ash plumes have been characterized by their high depolarization ratio, which is continue during June and July. The time series of the backscattering ratio had three peaks with a period of about 20 days. The peak backscattering ratios were 8.71 at 10.6 km on 11 June, 8.63 at 11.63 km on 24 June, 6.00 at 11.08 km on 6 July, respectively. The optical depth of the volcanic aerosols was 0.45 on 11 June that started the observation, 0.31 on 23 June and 0.12 on 5 July. A high depolarization ratio after 20 days of the eruption indicates that the volcanic aerosols have few spherical sulfuric acid particles, and a small wave number length dependence value indicates that the volcanic aerosols have large particles. The impact of the volcanic aerosols on the GOSAT product will be presented.

Keywords: aerosol lidar, volcanic aerosol, GOSAT

The Amazonian Carbon Observatory Network

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Despite its important role for the global carbon cycle, current understanding of the Amazonian, and more broadly the tropical, carbon cycle is poorly constrained by observations which result in large uncertainties in predictions of the fate of the Amazonian carbon budget under a warming climate. Since 2012, the Amazon region has been the focus of major UK and Brazilian research projects that aim at improving our knowledge of the Amazonian carbon cycle using detailed, aircraft observations of CO2 and CH4 at four sites. These measurements are a great advance, but they are realized only twice per month. Space-borne measurements have the ability to fill observational gaps and to complement such in-situ datasets and thus to improve the spatial and temporal coverage over regions such as the Amazon. It is essential, however, that such space-based observations are properly tied to the World Meteorological Organization (WMO) reference standard to ensure acceptance of space-based datasets by the carbon cycle community and to prevent misleading results on regional carbon budgets. The central aim of the Amazonian Carbon Observatory Network is to bridge the gap between in-situ and remote sensing observations and communities and to evaluate the feasibility of remote sensing of greenhouse gas (GHG) concentrations for the purpose of GHG flux monitoring over Amazonia to improve our understanding of the Amazonian carbon cycle and to increase our ability for observing tropical carbon fluxes.

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

The GreenHouse gas Observations in the Stratosphere and Troposphere (GHOST) Instrument

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The tropospheric distribution of greenhouse gases (GHGs) is determined by surface flux variations, atmospheric chemistry and transport processes over a spectrum of spatial and temporal scales. Atmospheric transport errors adversely affect surface fluxes inferred from GHG concentration measurements from surface, airborne or satellite instruments using an inverse model: uncharacterized transport model errors can result in significant bias of surface flux estimates. In the framework of the UK NERC project Co-ordinated Airborne Studies in the Tropics (CAST), we develop and fly a novel, compact short-wave IR (SWIR) spectrometer for the Global Hawk to collect observations of tropospheric CO_2, CO, CH_4, H_2O columns and the HDO/H_2O ratio over the ocean to address the need for large-scale, simultaneous, finely-resolved measurements of key species. These gases have a range of lifetimes and diverse source processes and their tropospheric columns will reflect the vertically integrated signal of vertical and horizontal transport. GHOST will also provide a unique validation opportunity for space-based GHG column observations. In this paper, we will discuss the GHOST project and its objectives and we will give an overview of the instrument concept and development

Keywords: carbon dioxide, methane, new instrumentation, validation

Mapping greenhouse gas emissions in the Los Angeles basin by remote sensing using a Fourier Transform Spectrometer on Mount Wilson

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Megacities, such as Los Angeles, are significant sources of anthropogenic greenhouse gases (GHGs), therefore it is critical to quantify their emissions. Here we present measurements of CO_2 and CH_4 by ground-based remote sensing from an elevated platform. At the California Laboratory of Atmospheric Remote Sensing (CLARS) on Mount Wilson in Southern California, a Fourier Transform Spectrometer (FTS), located at 1.7 km ASL, points downward at 28 different targets in the Los Angeles basin to measure the slant column abundances of CO_2, CH_4, N_2O, CO and O_2 using reflected sunlight in the near-infrared regions. This technique allows the spatial coverage of the Los Angeles basin at different times of the day. The column abundances above Mt. Wilson are also measured using a spectralon plate. The basin path-averaged dry-air mixing ratio, XCO_2 and XCH_4, showed significant diurnal variability due to emissions. Using the Spectralon measurements, which have no diurnal pattern, the contribution above Mt. Wilson is subtracted in order to calculate the basin contribution assigned to anthropogenic emissions. Here we show the spatial variability of the CH_4:CO_2 ratios in the air mass originating from the Los Angeles basin and comparisons with the ratios calculated from in-situ and total column data.

Keywords: CO_2, CH_4, anthropogenic emissions, cities

Characterization of GOSAT TANSO Level 1 V160.160 TIR spectra

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The Greenhouse Gases Observing Satellite (GOSAT) is a Japanese mission to monitor greenhouse gases such as CO_2 and CH_4 from space. The GOSAT was launched on 23 January 2009 and obtains normal operation data over 4 years. The FTS covers wide wavelength range from SWIR 3 bands to TIR band from 5.5 to 14.3 micrions by simultaneous observations.
The latest FTS Level 1 product was upgraded to V.160.160 in April 2013. Major improvements are in the TIR band spectral calibration as follows. 1) Deep space (DS) view obscuration is not effective because pointing anomaly offset is less than the DS window clearance. 2) Polarization parameters of mirrors, beam-splitters, dichroic filters are optimized at observation and calibration incident angles after checking the pre-flight test results. 3) Blackbody emissivity is measured precisely in heated-halo method collaborated with Univ. Wisconsin. Also, inner radiation is estimated with the view factor of blackbody. 4) Blackbody monitoring temperature decreases 0.1K around 10degC after improvement of engineering conversion table. 5) DC offset gradually changes on orbit by monitoring in DS observation.
Finally, we estimate the calibration uncertainty of V.160.160 in the TANSO-FTS TIR observation with consideration of measurement uncertainty of polarization, detector non-linearity, and blackbody.

Keywords: GOSAT, Level 1, TIR

Profiles of CO_2 and CH_4 retrieved from GOSAT/TANSO-FTS thermal infrared spectra using an improved algorithm

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The Thermal and Near-infrared Sensor for Carbon Observation Fourier Transform Spectrometer (TANSO-FTS) on board the Greenhouse Gases Observing Satellite (GOSAT) simultaneously observes column abundances and profiles of CO_2 and CH_4 in the same field of view, from the shortwave infrared (SWIR) and thermal infrared (TIR) bands, respectively. At this time, the version 00.01 (V00.01) data of the TIR L2 standard CO_2 and CH_4 products retrieved from V100.100 L1B spectra have been released to the public; however, their release was limited to three pressure levels. There is a relatively large bias in mid troposphere in the CO_2 product. We have been developing a new L2 algorithm for retrieving CO_2 and CH_4 profiles from the latest TIR L1B spectra (V150.150). Our new L2 retrieval algorithm adopts a non-linear Maximum a Posteriori (MAP) method with linear mapping and simultaneously retrieves temperature, surface temperature, surface emissivity, and other gases such as water vapor, ozone, and nitrous oxide. We use 7-8 micron band for CH_4 retrieval and 10 and 14-15 micron bands for CO_2 retrieval. We assume that the magnitude of the bias in the TIR L1B spectra correlates with its radiance and utilize the correlation to reduce the CO_2 bias seen in mid troposphere.

Keywords: GOSAT, thermal infrared, carbon dioxide, methane, retrieval algorithm

GOSAT TIR Band Inter-calibration with Satellite Infrared Sensors

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The UW-Madison in coordination with JAXA have completed a three year assessment of the GOSAT TIR band inter-calibration with the AIRS sensor on the NASA Aqua platform and the IASI sensor on the MetOp platform. The preliminary results of these comparisons will be presented at this meeting. Detailed assessment of the 15 micron CO_2 emission band indicates TANSO FTS TIR brightness temperature agreement with AIRS and IASI to about 0.5 K for processing version 150150. Residual cold scene biases were detected in the 8 to 10 micron window region at very cold scene temperatures, less than 230 K. These differences are expected to be reduced with the changes included in the next ground processing version update, which includes improved polarization corrections and internal calibration target emissivity characterization. The TANSO FTS internal blackbody was measured at UW-SSEC and uncertainty assessment of the spectral emissivity will be presented. Suggested improvements to the flat plate TANSO FTS blackbody design will be presented for consideration in GOSAT-2 designs.

Keywords: GOSAT, TANSO FTS, calibration, satellite inter-calibration, carbon dioxide

Quantification of radiative forcing of CO_2 and Absorbing Aerosol from GOSAT with the aid of Asia Carbon Tracker

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Radiative forcing is an important parameter to understand the climate change mechanism. Greenhouse gases and light absorbing aerosols are known to play a major role in increase in global average radiative forcing. However, many investigations have been carried out for better quantification of the radiative forcing of these atmospheric constituents. As a means of such efforts, in this present study, radiative forcing values of CO_2 and the absorbing aerosol have been quantitatively estimated, respectively utilizing Greenhouse Gases Observing Satellite (GOSAT) measurement data with the aid of Asia Carbon Tracker. In addition, this study presents an integrated aerosol and CO_2 algorithm using the level 1B data from both Thermal And Near-infrared Sensor for carbon Observation-Cloud and Aerosol Imager (TANSO-CAI) and Fourier Transform Spectrometer (TANSO-FTS). The CO_2 algorithm is based on the optimal estimation method. It also uses Carbon Tracker-Asia simulation data as inputs for a Priori, which are especially optimized for the East Asia domain. Combination of aerosol and CO_2 retrieval algorithms are expected to decrease CO_2 retrieval errors and increase the number of retrieved CO_2 products by reducing the uncertainties derived from high aerosol load. Therefore, this integrated algorithm is thought to be effective, in particular, on East Asia where the heavy aerosol load is persistently present.

Keywords: carbon dioxide, absorbing aerosol, radiative forcing, GOSAT

PSC and cirrus cloud detection over the high latitudes using thermal infrared spectra observed by TANSO-FTS/GOSAT

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Cloud and Aerosol Imager (CAI) which is one of the instruments onboard GOSAT and has sensitivity for reflected sun light ranged from ultraviolet to near infrared doesn't detect optically thin clouds accurately enough. On the other hand, Fourier Transform Spectrometer (FTS) which is also one of the instruments on GOSAT has the band observing thermal emission and the cirrus detection techniques in tropical and mid latitude had been developed. However, there are a few researches about that in high latitude that because of extremely low temperature surface and in addition, polar stratospheric clouds (PSCs) which is optically thinner than cirrus occur in lower stratosphere. Therefore, we modified CO_2 slicing method which is the one of cirrus detection technique to detect optically thin clouds globally including PSCs in high latitudes. This technique uses two wavenumber channels and these channel combinations were optimized for several atmospheric conditions based on the simulation using Polarized radiance System for Transfer of Atmospheric Radiation (Pstar). We show cloud top height distribution derived globally by this method and comparison with CALIPSO observation in the Antarcic.

Research Topic : CO_2 slicing method, cirrus, PSCs

Evaluating the benefits of in situ, TCCON, and GOSAT CO_2 measurements using independent data comparisons

D. Baker, T. Oda

We evaluate the constraint on surface sources and sinks of CO_2 provided by ACOS v2.10 GOSAT column CO_2 retrievals, ground-based column CO_2 retrievals from the TCCON network, and *in situ* CO_2 measurements from NOAA's surface network and routine aircraft profiles. Each data type will be evaluated by comparing the optimized CO_2 concentrations given by assimilating that data type by itself to the concentration measurements given by data types left out of each inversion. The biases in each data type relative to each other will be assessed and removed in computing the statistics of the fit, which are computed across a range of spatial and temporal scales.

For our prior, we use both optimized and projected fluxes for 2009-2011 from CarbonTracker (2011 release) run forward through the PCTM transport model at 1.0°x1.25° resolution (lat/lon). We then assimilate the different data products individually (i.e. GOSAT-only, TCCON-only, etc.) to solve for 3-day CO_2 flux corrections on a 3.0°x3.75° grid, using our variational data assimilation approach. Before assimilating the GOSAT data, we apply a bias correction consisting of a 3-parameter fit for each of three data types: ocean glint, high-gain land, and medium-gain land.

Impact of high resolution meteorological fields on simulation of high frequency variability of CO_2 concentration using FLEXPART with 1km flux maps

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This study aims at generation and application of global high resolution meteorological fields to facilitate resolving high frequency variability of CO_2 concentrations using Lagrangian particle dispersion model FLEXPART using high resolution (1km) flux fields. The surface CO_2 flux datasets include the three major individual components of terrestrial, oceanic and fossil fuel fluxes. The background concentrations of CO_2 are provided by an off-line global atmospheric tracer transport model (NIES-TM). High resolution meteorological fields are generated by the Non-hydrostatic Icosahedral Atmospheric Model (NICAM) at 28km spatial resolution using nudging to NCEP Final Analyses data. The coarse resolution simulation is carried out with 1.25 degree JCDAS meteorological data for the same period and compared with observed concentrations.

Keywords:carbon dioxide, transport

Developing adjoint of the coupled Eulerian-Lagrangian transport model

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During the last decades an observational network of increasing density is being established, measurements on board of ships and airplanes as well as space-borne observations are also becoming available to monitor the greenhouse gases in the atmosphere. Hence such observations provide a possibility to estimate their sources and sinks in more regions. In order to link the surface fluxes to the atmospheric concentration observations, an accurate model of the atmospheric transport and inverse modeling technique are needed. A number of studies have addressed improvements to the inverse methods of the atmospheric transport. The challenging task is using the information from a spatially sparse observational network in an optimal way to derive regional flux estimates together with an estimated range of confidence.

Here we present a development of an inverse modeling system employing an adjoint of National Institute for Environmental Studies (NIES) three-dimensional transport model (TM) coupled with a Lagrangian plume diffusion model. The adjoint has been constructed automatically in the ”reverse mode” of automatic differentiation by means of the Transformation of Algorithms in Fortran (TAF) software (http://www.FastOpt.com).

NIES TM is a three-dimensional atmospheric transport model, which solves the continuity equation for a number of atmospheric tracers on a grid spanning the entire globe. Spatial discretization is based on a reduced latitude-longitude grid and a hybrid sigma-isentropic coordinate in the vertical. NIES TM uses a horizontal resolution of 2.5°×2.5°. However, to resolve synoptic-scale tracer distributions and to have the ability to optimize fluxes at resolutions of 0.5° and higher we coupled NIES TM with the Lagrangian model FLEXPART. The Lagrangian component of the forward and adjoint models uses precalculated responses of the observed concentration to the surface fluxes and 3-D concentrations field simulated with the FLEXPART model.

NIES TM and FLEXPART are driven by JRA-25/JCDAS reanalysis dataset, with PBL heights provided by ERA interim reanalysis.

Forward and inverse modeling of CO_2

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To estimate surface fluxes of CO_2 for 2009-2010 using weekly surface discrete air samples (NOAA flasks) and space-borne (GOSAT) retrievals a coupled Eulerian-Lagrangian model (GELCA) was applied. This model contains the langrangian transport model FLEXPART and the eulerian taransport model NIES TM. In this work two different X_{CO2} retrieval products were used for flux inversion (PPDF-S and standard L2 product). Adjustments for each source are represented as a linear combination of main flux components according to surface gas exchange (using empirical orthogonal functions). As prior fluxes for different kinds of sources we used Vegetation Integrative SImulator for Trace gases (VISIT) for the biosphere, an ocean transport model with pCO_2 data and 4D-var assimilation system for ocean-atmosphere exchange, the Global Fire Emissions Database (GFED) for biomass burning emissions, and the ODIAC database for anthropogenic emissions. Due to the huge number of observations per month (6000-8000) we used a Fixed-Lag Kalman Smoother for solving the inverse problem that allows us to estimate monthly fluxes successively according to assimilation window. Results were presented as 2D fields of monthly surface fluxes for each kind of source with 1 by 1 degree resolution and estimated annual total global fluxes. Model concentrations with optimized CO_2 fluxes have been compared with independent station measurements over Siberia. Our calculations show significant uncertainty reduction of fluxes when GOSAT observations are included.

Lagrangian trajectories with turbulence parameterization were applied to simulate the CO_2 and relative humidity vertical profiles over Fyodorovskoe (56^0N;33^0E) where aircraft observations of these parameters were conducted and CO_2 vertical profiles over Domodedovo airport ($55,4^0$N;$37,9^0$E) to compare them to aircraft observations obtained in frame of CONTRAIL Project. We applied the modified trajectory model to calculate backward trajectories based on ERA-Interim winds and initialized using ERA-Interim specific humidity and CarbonTracker CO_2 concentrations. The comparisons of modeled and observed profiles demonstrate the better agreement than in the case of bilinear interpolation of surrounding gridded values to observation point at the time of observations. Such an improvement of forward modeling can reduce the uncertainties of CO_2 flux inversion.

An approach of carbon dioxide concentration simulation using GELCA model and ensemble meteorology is presented. Ensemble meteorology was created by combining of JCDAS wind fields and ESRL/PSD GEFS Reforecast Version 2

dataset. JCDAS data were interpolated from original T106 Gaussian grid to regular 1.25°×1.25° grid, the vertical structure has 40 levels and was used without any modifications. ESRL/PSD GEFS Reforecast 2 includes 10 perturbed forecast members, ensemble mean and one control forecast with 1.0°×1.0° horizontal resolution; the vertical structure is described by 12 pressure levels, 4 hybrid levels near surface and 10m level. To create JCDAS ensemble meteorology ESRL/PSD GEFS Reforecast 2 winds were interpolated to 1.25°×1.25° grid. Flux footprints were simulated with Flexpart model for each of the 10 ensemble members and the CO_2 concentrations were simulated using GELCA, footprints and surface carbon dioxide emissions. We have used these 10 different concentrations and applied Kalman filter to obtain the optimal weights of the linear combination for the ensemble members resulting in a best fit to the observations within a fixed size time window of several days.

Keywords: GOSAT, carbon dioxide, modeling

Regional CH_4 flux estimates based on GOSAT SWIR L2 and ground-based observations

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Monthly CH_4 fluxes for 43 regions in 2009-2010 were estimated by an inverse model using bias-corrected GOSAT SWIR Level 2 XCH_4 retrievals and ground-based CH_4 observations archived at WDCGG. XCH_4 bias was approximated with second-order polynomial function of latitude and month (Bergamaschi et al. 2007). We used interannually varying CH_4 emissions by the GFED and VISIT ecosystem model and the interannually repeating EDGAR CH_4 emissions and chemical sink fields prepared by the TransCom-CH_4 project in a forward simulation by the NIES transport model. The inverse problem of optimizing the fluxes was solved with a fixed-lag Kalman smoother. We compared the inversion results using the two different datasets to assess the utility of GOSAT XCH_4 data in flux estimates and found good fit to the ground-based data with chi-square values of 0.84 and 0.91 with fluxes estimated using ground-based data only and both ground-based and GOSAT data, respectively. The inversion based on GOSAT data yielded higher wetland and rice emissions over tropical Africa, northern tropical Asia, the Amazon Basin and lower anthropogenic emissions over the Arabian Peninsula and India, leading to decreasing the flux uncertainties (>20%) compared with flux uncertainties estimated based on ground-based data only.

Keywords: GOSAT, methane flux, inverse modeling

Development of the GOSAT-2 FTS Simulator

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The Greenhouse Gases Observing Satellite 2 (GOSAT-2), which is a successor mission to the GOSAT, is planned to be launched in FY 2017. The Fourier Transform Spectrometer (FTS) onboard the GOSAT-2 is a primary sensor to observe sunlight reflected from the Earth's surface and retrieve column amounts of carbon dioxide (CO_2) and methane (CH_4) from the obtained radiance spectra. We have been developing a tool, named GOSAT-2 FTS simulator, which is capable to simulate the spectral radiance data observed by the FTS using Pstar2 code for radiative transfer calculation. The purpose of the GOSAT-2 FTS simulator is to obtain data for utilizing the sensor specification, the optimization of parameters for Level 1 processing, and the improvement of Level 2 algorithms. The GOSAT-2 FTS simulator, composed of the six components: 1) overall control, 2) FTS onboarding platform, 3) FTS input spectral radiance calculation, 4) FTS (Fourier transform), 5) L1B processing, and 6) L1B data output, has been installed on the GOSAT Research Computation Facility (GOSAT RCF). We will present an overview and initial results of the GOSAT-2 FTS simulator.

Keywords: GOSAT-2, FTS, simulator

Estimation of CNES / MicroCarb performances at level 1 and level 2

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The objective of the CNES / MicroCarb mission is to retrieve the CO2 dry air mass mole fraction (XCO2) with a high accuracy, in order to better quantify the sources and sinks of CO2 through assimilation into atmospheric transport models. This high accuracy has been the main driver for the requirements applied to the instrumental and satellite design during phase A. In this presentation, we expose the requirements and performances for level 1 products (calibrated spectra) in term of spectral resolution, instrumental signal to noise and pseudo-noises. Geometric, radiometric, spectral and polarimetric aspects are considered. Then, we present the estimation of MicroCarb performances at level 2 (XCO2) in terms of accuracy and biases. For that purpose, we apply an optimal estimation in several geophysical and instrumental cases. A comparison with the soon launched NASA/OCO-2 mission is also performed. A quick overview of the impact on the level 4 (fluxes) will be finally presented.

Keywords: Microcarb, carbon dioxide, retrieval, performances, CNES

Potential of the remote sensing of CO_2 by Sentinel-5 for the estimate of CO_2 natural and anthropogenic fluxes

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The Sentinel-5 instrument on-board the MetOp satellite could measure vertically integrated CO2 (XCO2) mixing ratios with a near global daily coverage at 5-10 km horizontal resolution. In this study, Observing System Simulation Experiments using global and local atmospheric inversion systems are conducted to assess the potential of XCO2 data from Sentinel-5 for improving the estimates of CO2 natural fluxes at global to continental scale and CO2 anthropogenic emissions in the Paris area. These systems are based on a modelling of the CO2 atmospheric transport at ~3° and 2 km horizontal resolution respectively. The potential of Sentinel-5 is compared to that of other satellite missions and of in situ networks. The statistical combination between the information from these different networks is also considered. A special care is given to the configuration of realistic biases and random errors in the XCO2 measurements and to the estimate of their impact for the retrieval of CO2 fluxes. At global scale, such biases would likely prevent the satellite from significantly improving the knowledge on natural fluxes. At urban scale, the large swath and the relatively high spatial resolution of Sentinel-5 seem to provide a high potential for the estimation of the emissions few hours before the satellite observation.

Keywords: carbon dioxide, Sentinel-5, atmospheric inversion, natural fluxes, anthropogenic emissions

Satellite remote sensing of methane: Sentinel-5 Precursor in Perspective of GOSAT

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The Sentinel-5 Precursor (S5P) instrument, to be launched in 2014 by the European Space Agency (ESA), will continue and complement the measurement series methane column averaged dry air mole fraction (XCH4) from SCIAMACHY and GOSAT. The key improvement of S5P XCH4 measurements compared to earlier instruments is its very good spatial coverage (global coverage within one day). The S5P retrieval algorithm for XCH4 is based on the RemoTeC approach (a joint development between SRON Netherlands Institute for Space Research and the Karlsruhe Institute for Technology, KIT) to account for light path modification by aerosols and thin cirrus clouds. Two spectral bands are used: the O2 A-band and the 2300 nm Short Wave Infra Red (SWIR) band. We will discuss the expected performance of S5P XCH4 retrievals based on extensive retrieval simulations. Also, we discuss the expected performance of S5P in perspective of GOSAT RemoTeC retrievals. We present a validation of retrieved XCH4 from GOSAT with ground based measurements of the Total Carbon Column Observing Network (TCCON) and investigate possible correlations of the XCH4 error with geophysical parameters. Based on validation with TCCON we demonstrate that the precision and accuracy of the retrieved XCH4 is respectively about 0.8% and 0.25%. We will show that for S5P a similar performance may be expected.

Analysis of Pulsed Lidar Measurements of Atmospheric CO_2 Column Absorption from the ASCENDS 2011 Airborne Campaign

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We have developed a pulsed IPDA lidar that measures the 1572.33 nm CO_2 absorption line with 30 wavelengths across the line. Our approach gives us height-resolved atmospheric backscatter information (shown in Fig. 1), allowing us to resolve lidar reflections from different cloud layers and the ground and therefore determine the PBL. We can simultaneously measure the column-averaged CO_2 column depth to cloud layers and ground, and sample obtaining atmospheric CO_2 profiles. Measuring the line at multiple wavelengths allows determining its spectroscopic features.

We conducted a series airborne measurements in August 2011 as part of the NASA ASCENDS campaign. We flew over a variety of conditions, including broken and cirrus clouds. Analysis of the measurements show measurement precision is 0.2% (<1 ppmv), and the accuracy of the column averaged CO_2 concentration appears limited by the natural variation of the CO_2 in the atmosphere. Data from a flight over Iowa, shows a sharp decrease in the CO_2 concentration below the PBL due to the summer biosphere. Analysis of the measured line shape yields the linewidth (accurate to <20 MHz) and line-center (<6 MHz, shown in Fig. 2), and thus see Doppler shifts due to winds and the airplane speed. These results will be described in the presentation.

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

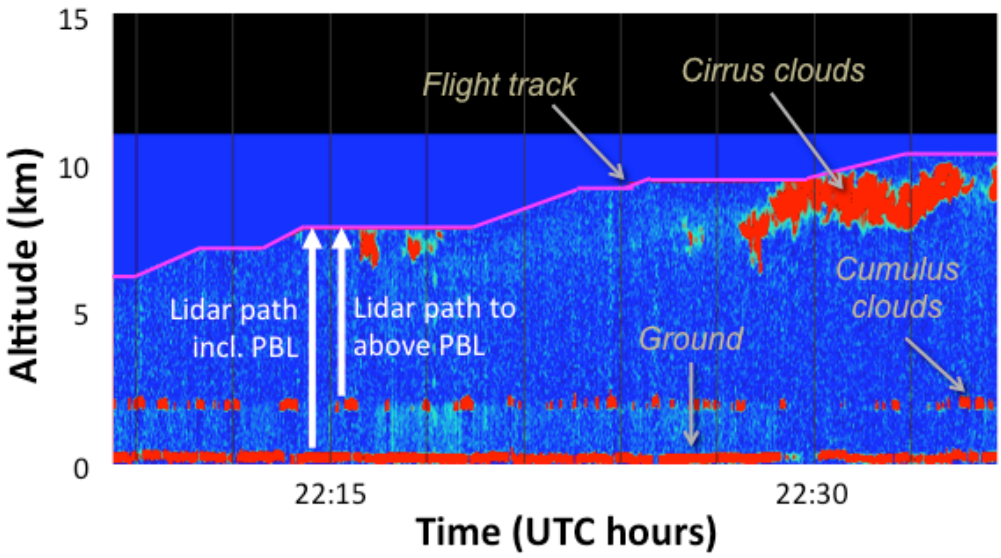

Figure 1: Sample backscatter data from a flight segment over Iowa, USA on Aug. 10 2011 showing lidar reflections off the ground, cirrus and cumulus clouds. Simultaneous absorption measurements of lidar reflections from above and below the planetary boundary layer (PBL) indicate a 10 ppm reduction in the CO_2 concentration below the PBL.

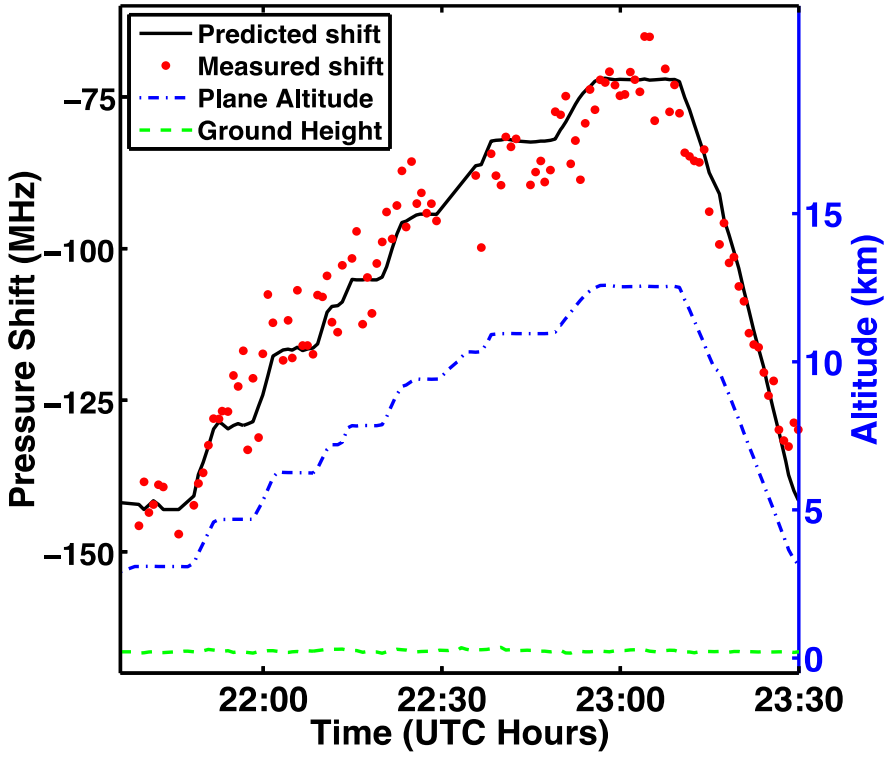

Figure 1: Change in position of line-center due to the varying pressure shift from the changing atmospheric column, arising out of the aircraft changing altitude from 3 to 12 km above ground. The measured position agrees with the prediction to within 6 MHz.

Pulsed Lidar Measurements of Atmospheric CO_2 Column Absorption from the ASCENDS Airborne Campaigns

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We conducted airborne campaigns of our pulsed lidar system in August 2011 and February-March 2013 as part of the NASA ASCENDS program, flying over a variety of conditions, including clouds. Our instrument uses an IPDA (Integrated-Path, Differential Absorption) approach probing 30 wavelengths across the 1572 nm CO_2 absorption line. Although our measurement precision is 0.2% (<1 ppmv), our measurement accuracy of the column averaged CO_2 concentration is limited by the natural variation of the CO_2 distribution in the atmosphere.

Our pulsed approach gives us height-resolved (from time-of-flight) atmospheric backscatter information (shown in Fig. 1), allowing us to resolve lidar reflections from different cloud layers and the ground and therefore determine the PBL. We can simultaneously measure the column-averaged CO_2 concentration to each individual cloud layer and ground, thereby obtaining atmospheric CO_2 profile information. Data from a flight over Iowa, USA in August 2011 shows a sharp decrease in the CO_2 concentration below the PBL due to the summer biosphere.

By probing multiple wavelengths on the absorption line, we can also measure spectroscopic features of the CO_2 absorption in the atmosphere with unprecedented accuracy, such as the linewidth (accurate to <20 MHz) and line-center (<6 MHz, shown in Fig. 2), and thus see Doppler shifts due to winds and the airplane speed.

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

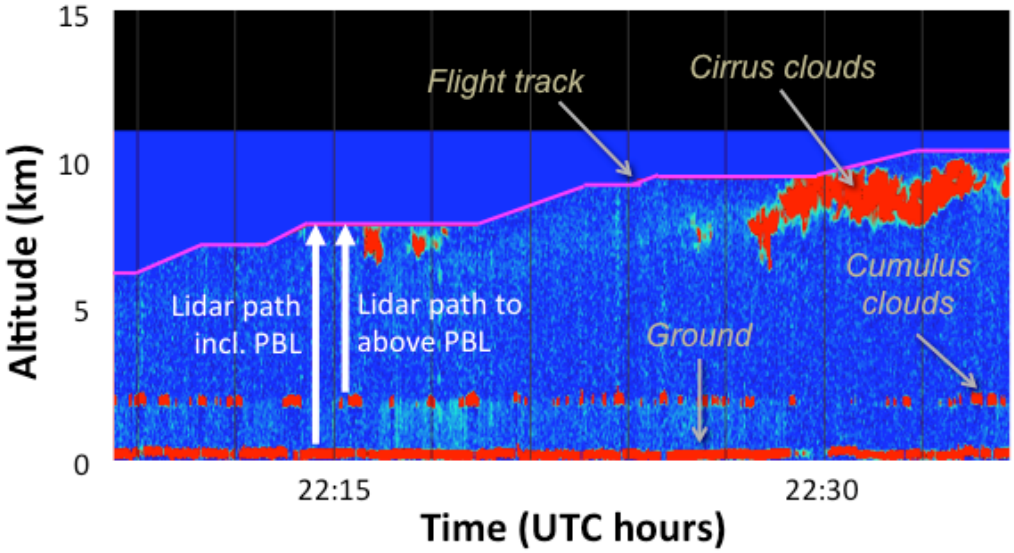

Figure 2: Sample backscatter data from a flight segment over Iowa, USA on Aug. 10 2011 showing lidar reflections off the ground, cirrus and cumulus clouds. Simultaneous absorption measurements of lidar reflections from above and below the planetary boundary layer (PBL) indicate a 10 ppm reduction in the CO_2 concentration below the PBL.

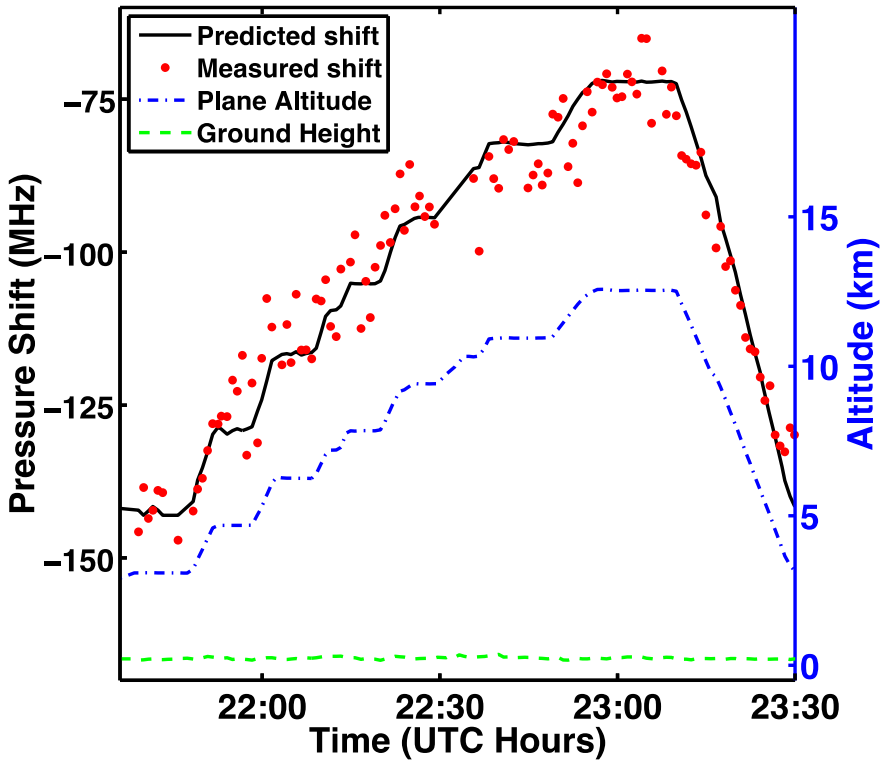

Figure 3: Change in position of line-center due to the varying pressure shift from the changing atmospheric column, arising out of the aircraft changing altitude from 3 to 12 km above ground. The measured position agrees with the prediction to within 6 MHz

Airborne lidar measurements of atmospheric pressure for the ASCENDS mission using the oxygen A-band at 765 nm

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Global greenhouse gas mixing ratios are needed to better understand climate change and possible effects on our planet. These ratios are expressed with respect to atmospheric dry air number density. Accurate mixing ratio measurements require precise knowledge of the dry air number density.

We report here on efforts to determine dry air number density through oxygen absorption measurements at 764.7 nm. Oxygen is stable and uniformly mixed in the atmosphere. Therefore, oxygen absorption measurements can be used to infer dry air number density and to calculate mixing ratios for carbon dioxide or methane.

Our measurement technique uses integrated path differential absorption (IPDA) LIDAR with an Erbium Doped Fiber Amplifier (EDFA) laser system, a second harmonic generator (SHG), and a single photon counting module (SPCM). The system measures atmospheric transmission at multiple on- and off-line wavelengths in the O2 A-band near 764.7 nm. Our retrieval algorithm uses meteorological and aircraft altitude information to fit the experimental O2 absorption to atmospheric models and correlates pressure changes with changes in the measured absorption profile. We have demonstrated O2 absorption measurements for fixed horizontal paths and from a NASA DC-8 aircraft from 3 to 13 km. This paper will present airborne measurement results from 2011 and 2013 flight campaigns for the ASCENDS program.

Keywords: ASCENDS, carbon dioxide, oxygen

Retrieval of Vertical Structure of Atmospheric CO_2 Concentration from Airborne IPDA Lidar Measurements of CO_2 and O_2 Absorption during the 2011 ASCENDS Science Campaign

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NASA Goddard is developing an integrated-path, differential absorption (IPDA) lidar approach to measure atmospheric CO_2 concentrations from space as a candidate for NASA's ASCENDS mission. The approach uses pulsed lasers to measure both CO_2 and O_2 absorption simultaneously in the vertical path to the surface at a number of wavelengths across a CO_2 line at 1572.335 nm and the O_2 line doublet near 764.7 nm. Measurements of time-resolved laser backscatter profiles from the atmosphere allow the technique to estimate column CO2 and O2 number density to cloud tops in additional to the ground. This allows sampling the vertical structure of CO2 and O2 when broken and/or thin clouds are present. This additional information can improve absorption line fits and estimates of column-averaged CO_2 and O_2 number density, and help identify sources/sinks of CO_2 near the surface.

We show some preliminary results of this capability using airborne lidar measurements from the summer 2011 ASCENDS campaign. These show simultaneous retrievals of CO_2 and O_2 column densities for laser returns from ground, low-altitude clouds and from cirrus clouds. CO_2 concentration in the planetary boundary layer and free troposphere are estimated and compared to those from in-situ CO_2 profiles measured during the campaign.

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

Carbon Monitoring Satellite (CarbonSat): Error analysis for XCO_2, XCH_4 and secondary products such as Vegetation Chlorophyll Fluorescence

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CarbonSat is one of two candidate missions for ESA's Earth Explorer 8 (EE8) to be launched around 2019. Using the most recent instrument and mission specification, an error analysis has been performed using the latest versions of algorithms for retrieving CarbonSat's primary geophysical products, which are the column-averaged dry air mole fractions of CO_2 and CH_4, denoted XCO_2 and XCH_4. This comprises the definition of relevant geophysical scenarios, radiative transfer and instrument simulations to generate simulated radiance spectra as will be measured by CarbonSat, and the application of retrieval algorithms. Error analysis results have been obtained for the CarbonSat's primary products XCO_2 and XCH_4, but also for its secondary products such as Vegetation Chlorophyll Fluorescence. Random errors are primarily a result of instrument noise and are standard output of the retrieval algorithms. Systematic errors (biases) are determined by computing the difference between the retrieved value and the true value known from the model atmosphere. Biases are caused by a number of potentially important error sources such as undetected thin cirrus clouds, aerosols and residual errors from imperfect spectral and radiometric calibration. In this poster results from a recent error analysis are presented focusing on nadir observations. First results for sun-glint observations over the ocean will also be presented.