GOSAT RETRIEVALS OF CH_4 AND CO_2 AND THEIR COMPARISONS TO GLOBAL CHEMISTRY TRANSPORT MODELS

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ABSTRACT

Global observations of total column CH_4 and CO_2 from space-based shortwave infrared measurements are well suited to improve our knowledge of the underlying surface fluxes. However, inferring these surface fluxes from total column data requires stringent levels of measurement precision and accuracy, representing a major challenge for the trace gas retrieval algorithms mainly due to spectral interference from atmospheric aerosols and clouds.

This paper presents global retrievals of CH_4 and CO_2 columns from the shortwave infrared bands of the GOSAT satellite for the years 2009 to 2012. The retrieved CH_4 and CO_2 columns have now reached a high level of accuracy and precisions (0.7% for XCH_4 and 0.6% for XCO_2) as is demonstrated from the validation of the retrieved CH_4 and CO_2 columns against observations from Total Carbon Column Observing Network (TCCON).

Global transport models are used to calculate the atmospheric concentrations of CH_4 and CO_2 based on a combination of emission inventories and biospheric fluxes from land surface models or alternatively on optimized surface fluxes obtained by assimilating in-situ observations from the surface networks. We have used the CH_4 and CO_2 columns from GOSAT to challenge model calculations from several state of the art global transport models and to diagnose the capability of the models to reproduce the regional spatio-temporal distributions of CO_2 and CH_4 as observed by GOSAT.

1. INTRODUCTION

The concentration of carbon dioxide has risen from pre-industrial levels of 280 ppm to present-day values in excess of 390 ppm. This increase is attributed to human activities such as combustion of fossil fuels and deforestation. The resulting change in atmospheric CO_2 concentrations is responsible for a change in global mean radiative forcing of 1.66 Wm^{-2}, with this value expected to continue to increase, drastically affecting our future climate.

Over a 20-year timescale, methane has a radiative forcing comparable to that of CO_2, making it the second most important anthropogenic greenhouse gas. This, along with the influence it has on tropospheric ozone and water vapour, means that it plays a key role in the Earth's atmosphere. However, recent unexpected changes in the methane growth rate have highlighted that there are still gaps in our understanding of the CH_4 budget [1], which can arise from the upscaling of the highly accurate, but sparse, surface concentration data to continental scales.

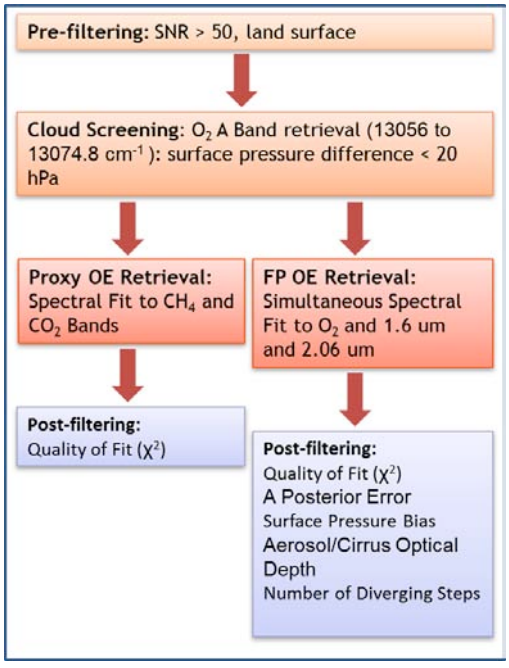

Figure 1. Schematic of the University of Leicester GOSAT retrieval processing chain. The left side describes the proxy XCH_4 retrieval with the right side describing the Full-Physics XCO_2 retrieval.

Global satellite retrievals of CO_2 and CH_4 can begin to address some of these issues. This work utilises the

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Japanese GOSAT satellite to provide global total columns of XCH_4 and XCO_2 between June 2009 and December 2011.

GOSAT was launched on 23rd January 2009 [2] by the Japanese Space Agency. The TANSO-FTS instrument on-board GOSAT has four spectral bands with a high spectral resolution (0.3 cm^{-1}), three of which operate in the SWIR (shortwave infrared) at around 0.76, 1.6 and 2.0 μm providing sensitivity to the near-surface.

The OCO 'Full Physics' retrieval algorithm was developed for the NASA Orbiting Carbon Observatory (OCO) mission to retrieve XCO_2 (dry-air column-averaged mole fraction of CO_2) from a simultaneous fit of SWIR O_2 and CO_2 bands [3,4]. The OCO algorithm has been modified to operate on GOSAT spectra and we use it to perform global retrievals of XCO_2 and XCH_4.

Fig. 1 shows a schematic of the retrieval process and highlights the two different retrieval streams, the "Full Physics" approach on the right and the "Proxy Methane" approach on the left. In brief, the difference between the two approaches is that whilst in the "Full Physics" approach we attempt to model the atmospheric scattering due to aerosols using our best a priori knowledge of the aerosol and to retrieve the various aerosol amounts, in the "Proxy" case we use the 1.6 um CO_2 to act as a proxy for the modified light-path due to scattering and hence ratio out the majority of scattering effects. In this case the XCH_4/XCO_2 ratio needs converting back into a VMR (volume mixing ratio) through the use of a CO_2 model. For more details on the retrieval approaches please see [5] and [6].

2. VALIDATION

The Total Carbon Column Observing Network (TCCON) is a series of ground-based Fourier transform spectrometers operating in the SWIR [7], performing a comparable measurement to that made by GOSAT, albeit from the surface. TCCON data are calibrated against in situ aircraft data, allowing them to be placed on the World Meteorological Organisation (WMO) scale.

Fig. 2 shows the correlation between the GOSAT XCO_2 (top) and XCH_4 (bottom) against the TCCON data at 12 different TCCON sites across various latitudes.

All GOSAT data within a ±5° box around each TCCON site is used to compare to the average TCCON data within ±2 hours of the GOSAT measurement.

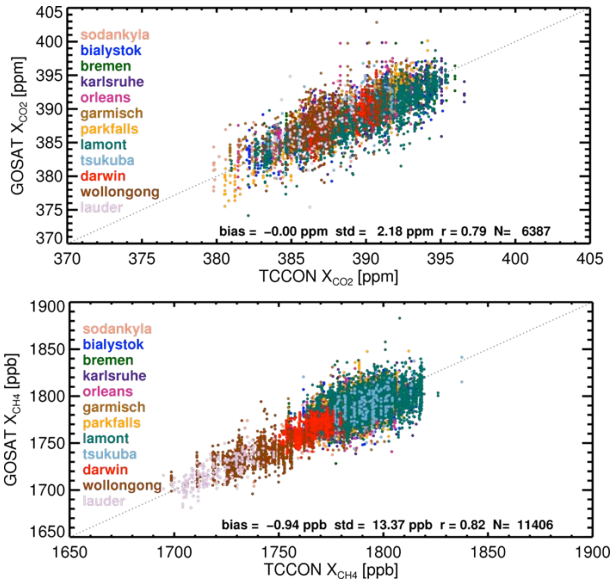

Figure 2. Comparison of the retrieved XCO_2 (top) and XCH_4 (bottom) to the TCCON validation data for 12 of the TCCON sites.

Overall a very good agreement is found against TCCON for both XCO_2 (r = 0.79) and XCH_4 (r = 0.82). As our GOSAT XCO_2 data is bias corrected, the overall bias to TCCON is 0 ppm and the standard deviation (an indication of the measurement precision) is 2.18 ppm. The XCH_4, which does not require a bias correction, has a small bias of -0.94 ppb with a standard deviation of 13.4 ppb.

This validation gives confidence in the quality of the GOSAT data around the TCCON sites but as will be discussed later, it is much harder to assess the quality of the data away from the TCCON stations in areas which are typically much more challenging for the retrieval (e.g. Sahara desert, South-East Asia).

3. CO_2 MODEL COMPARISONS

This section presents comparisons of the GOSAT XCO_2 retrieval to three different state of the art global chemistry transport models.

Fig. 3 compares GOSAT (top-left) to GEOS-Chem provided by the University of Edinburgh (top-right), CarbonTracker [8] provided by NOAA (bottom-left) and LMDZ provided by LSCE (bottom-right) for July 2009. All three models have been constrained by surface flask measurement and hence should provide a good estimate of XCO_2 in regions sampled by the flask network.

In general there is a good agreement between the satellite data and all three models but various differences are apparent, both to the satellite data but

also between each of the individual models.

The GOSAT data appears to be biased high over the Sahara desert region, likely related to desert dust aerosols impacting upon the retrieval. However, the models themselves also disagree over the desert region (cf. CarbonTracker and LMDZ in Fig. 3) and without any TCCON validation site in the area it remains difficult to assess the data in these regions.

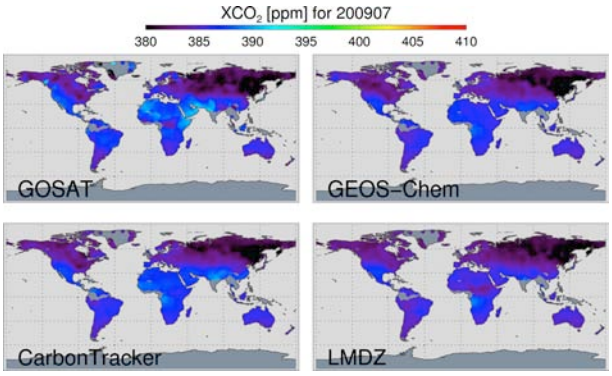

Figure 3. Comparison of global XCO_2 from GOSAT (top-left) to three state of the art global chemistry transport models for July 2009.

Fig. 4 shows the timeseries of the GOSAT XCO_2 against each of the different model runs over the tropical Africa region. All three models show good agreement with the satellite data, capturing the different features, primarily related to biomass burning in the region. However, CarbonTracker appears to underestimate the XCO_2 by several ppm in comparison to both the satellite data and the other model data.

As well as using the GOSAT data in conjunction with the models to investigate specific features and learn about the emissions, the GOSAT data can also assist in verifying some of the larger scale features in the model. Fig. 5 shows a comparison of the XCO_2 timeseries around the Wollongong TCCON station in south-eastern Australia. The GOSAT and TCCON data are in good agreement in both the phase and magnitude of the seasonal cycle (top-left). However, the GEOS-Chem data does not agree well in this area, with a much flatter distribution (top-right). By calculating the smoothed detrended annual cycle (bottom-left), it shows that GEOS-Chem vastly underestimates the strength of the seasonal cycle in this region, with the cause most likely due to model transport.

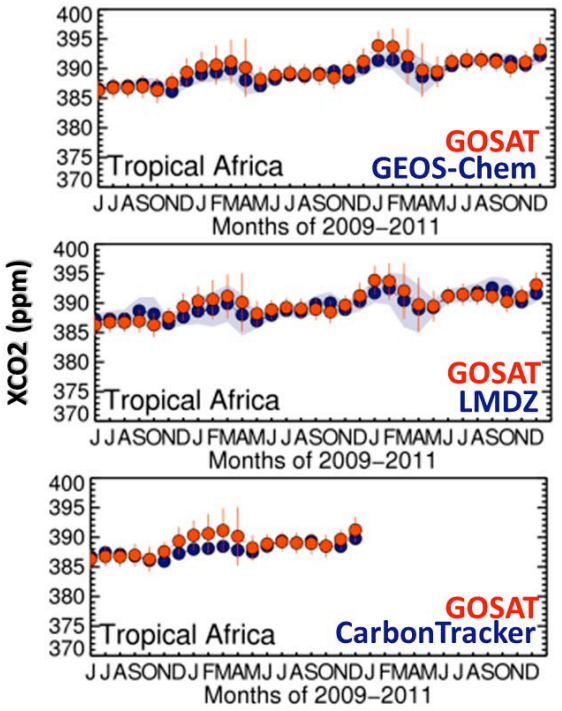

Figure 4. Timeseries of XCO_2 over Tropical Africa from GOSAT (red) against the model data (blue) for each of the models: GEOS-Chem (top), LMDZ (middle) and CarbonTracker (bottom).

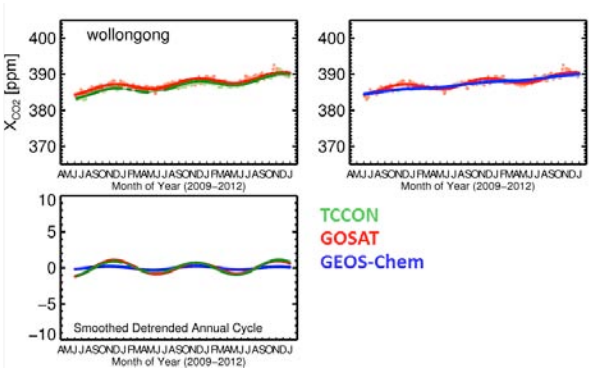

Figure 5. Comparison of the smoothed GOSAT XCO2 timeseries within ±5° of the Wollongong TCCON station against the TCCON data (top-left) and the GEOS-Chem model data (top-right). The lower panel shows the smoothed detrended annual cycle.

4. CH_4 MODEL COMPARISONS

The GOSAT proxy XCH_4 data as described in Section 1 is compared to model XCH_4 from two free-running global chemistry transport models, GEOS-Chem from the University of Edinburgh [9] and TOMCAT from the University of Leeds.

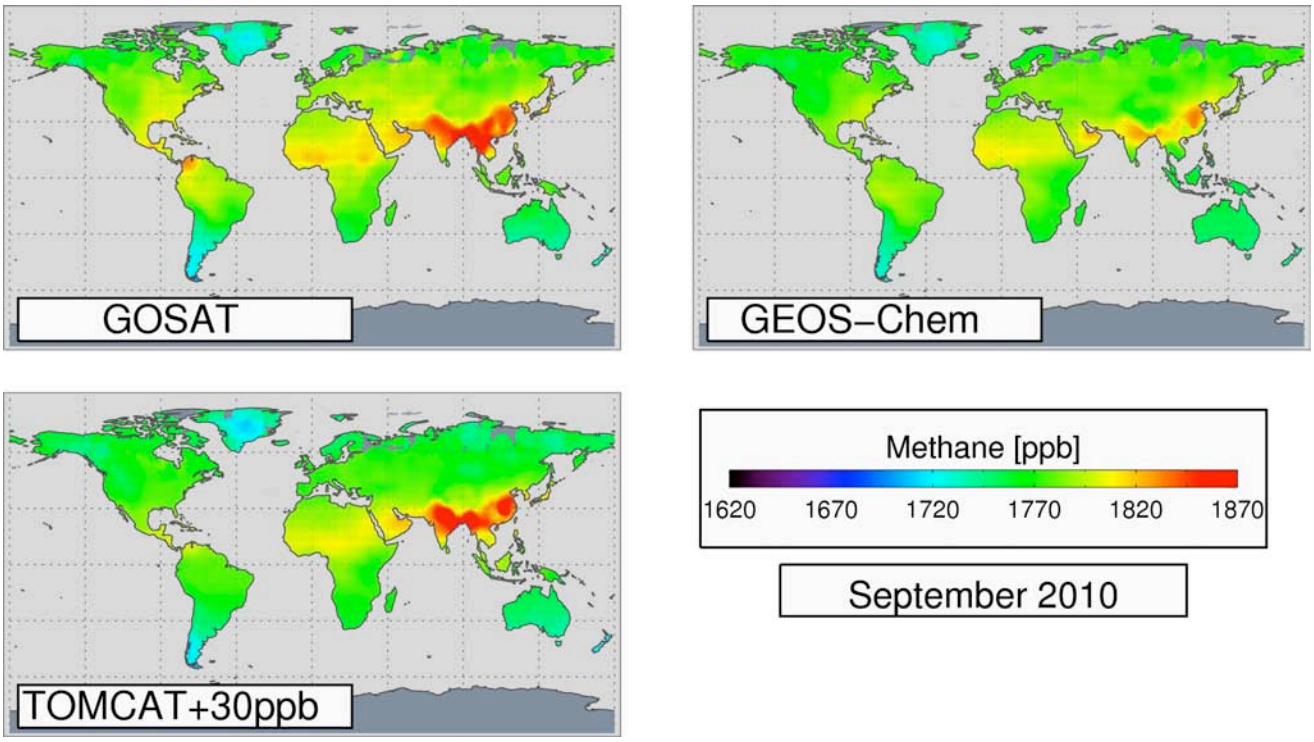

Figure 6. Comparison of global XCH_4 from GOSAT (top-left) to two state of the art global chemistry transport models for September 2010.

Initial comparisons of the two models, TOMCAT and GEOS-Chem with both the TCCON and GOSAT data indicated that TOMCAT had a global constant negative bias of approximately 30 ppb. This cause of this bias is still to be fully understood but as the purpose of this work is more focused on the spatio-temporal variations in the data, rather than the absolute values, a correction of 30 ppb is applied to all TOMCAT data included here.

4.1. Global Comparisons

Global comparisons between the three datasets (GOSAT, GEOS-Chem and TOMCAT) show a high degree of similarity but with occasional differences, especially in the magnitude of some emission sources.

Fig. 6 shows global maps of XCH_4 for September 2010. The large wetland and rice paddy emissions from South-East Asia are readily observed in all three datasets but the relative magnitude of the TOMCAT distributions appears to be in better agreement (after the previously mentioned constant offset correction). Whilst the GEOS-Chem model uses emissions based on [10], the TOMCAT model uses wetland emissions from the JULES earth system model.

4.2. Regional Comparisons

In order to examine these differences in greater detail, regional comparisons were also carried out, using the same regions as in [5]; Global, Northern Africa, Southern Africa, Australia, Amazon Basin, North America, South-East Asia and Russia.

Fig. 7 shows these regional comparisons for both GEOS-Chem (top) and TOMCAT (bottom). The three highlighted areas show time periods of particular interest.

In South-East Asia, the wetland and rice paddy emissions in August to November are evident from the GOSAT data as well as both model datasets, however the magnitude of the emissions in TOMCAT is in better agreement with the GOSAT satellite data. It should however be noted that South-East Asia is a particularly difficult region for the satellite retrieval so some care must be taken when interpreting the data in this region.

Boreal wetland emissions are observed during the same time period but in this instance it is GEOS-Chem which appears to show a similar magnitude to the satellite data, with TOMCAT underestimating.

Finally, the Amazon region, which is of particular interest for wetland emissions, again sees the best agreement between GOSAT and GEOS-Chem, with TOMCAT underestimating the emissions in this area. It is believed that this is potentially related to an issue with convection in the model, rather than in the JULES wetland emission database which in fact appears to often over-estimate the CH_4 emissions in the Amazon.

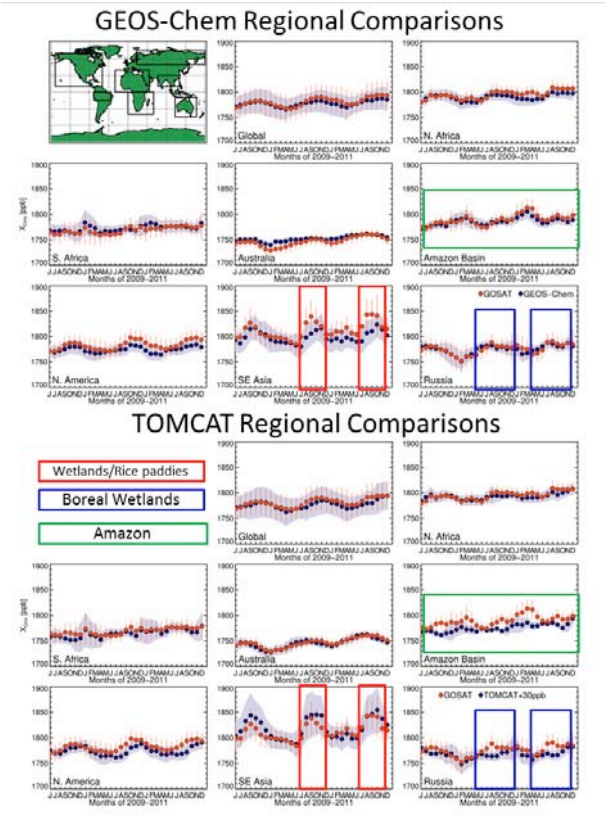

Figure 7. Timeseries of XCH_4 from GOSAT (red) against the model data (blue) for the GEOS-Chem model (top) and the TOMCAT model (bottom).

5. SUMMARY

In summary, this work presents some initial comparisons of GOSAT XCO_2 and XCH_4 to various global chemistry transport models with the intention of both assessing the quality of the GOSAT data and also beginning to understand the differences between the models themselves. These differences enable us to begin to understand the uncertainties in the different emission inventories used in the models. Initially this work has focused largely on the CH_4 wetland emissions used in the models but will also be extended to examine the CO_2 emissions in more detail.

6. REFERENCES

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7. ACKNOWLEDGMENTS

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