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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Elevated uptake of CO_2 over Europe inferred from GOSAT X_{CO_2} retrievals: a real phenomenon or an artefact of the analysis?" *by* L. Feng et al.

Anonymous Referee #1

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Manuscript "Elevated uptake of CO2 over Europe inferred from GOSAT XCO2 retrievals: a real phenomenon or an artefact of the analysis?" submitted by Feng et al. for publication in Atmos. Chem. Phys. (ACP) is addressing an important scientific issue and contains new material, which has not been published before. The topic is in principle appropriate for ACP and the paper is reasonably well written. However, I cannot recommend publication before the major (and several minor) issues listed below have been carefully addressed by the authors.

General comments:

My main problem with the paper is the following: In the title a question is asked and the abstract suggests that this question is addressed and answered, although the answer remains a bit unclear. Nevertheless, most readers will very likely conclude from the abstract that the answer is: Yes, this is an artefact (e.g., Abstract, page 1991, lines 9-10: "We show this elevated uptake over Europe could largely be explained by mis-fitting data due to regional biases"). The question is: What exactly is meant by the mentioned artefact? Here the authors refer primarily to one recent peer-reviewed publication and the Feng et al. paper casts doubt on the findings of that publication. The question in the title is related to a key conclusion from the recent paper "Satellite-inferred European carbon sink larger than expected" of Reuter et al., ACP (2014) (see Feng et al., page 1993, lines 8-11, see also below). Feng et al. are essentially aiming at addressing the question if the results shown in Reuter, et al. (2014) are "real . . . or an artefact of the analysis". To investigate this question is important but as shown below the analysis performed by Feng et al. is not appropriate to validate or invalidate the results presented in Reuter et al. (2014).

Feng et a. write (Abstract lines 20-22): "We find that 50–80% of the elevated European uptake in 2010 inferred from GOSAT data is due to retrievals outside the immediate European region, while most of the remainder can be explained by a sub-ppm retrieval bias over Europe". While these findings are relevant for the flux inversion method used by Feng et al., they do not permit to draw any conclusions with respect to the Reuter et al. findings for a number of reasons, for example, because Reuter et al. are not using any satellite data outside of Europe. Retrieval errors outside of Europe therefore cannot influence the findings of Reuter et al. As clearly explained in Reuter et al. (2014) they only used satellite data over Europe to avoid potential issues with non-European data. The analysis presented by Feng et al. is therefore not appropriate to answer the question posed in the title of the manuscript – at least not with respect to the Reuter et al. publication.

In this context it needs to be pointed out that the Reuter et al. (2014) paper is the relevant publication in the context of the Feng et al. paper as can be seen from, e.g., page 1993 lines 8-11: "Consequently, there is an ongoing debate about whether a recent study that shows a large European uptake of CO2 (Reuter et al., 2014) reflects a real phenomenon or is an artefact of uncharacterized regional biases".

Reuter et al. (2014) present a detailed assessment of the strength of the European carbon uptake due to terrestrial vegetation (focusing on the year 2010 as done in Feng et al.). They analyzed satellite data over Europe using several satellite-derived column-averaged dry-air CO2 mole-fraction ("XCO2") data products from SCIAMACHY/ENVISAT and TANSO-FTS/GOSAT (to demonstrate the robustness of their findings) and concluded that the European carbon sink is significantly larger than hitherto known from the analysis of (sparse) surface CO2 observations, namely 1.02 +/- 0.30 GtC/year for 2010 (Reuter et al., 2014) compared to earlier estimates of 0.45 +/- 0.4 GtC/year for 2010 (Chevallier et al., 2014), or 0.40 +/- 0.42 GtC/year for 2001-2004 (Peylin et al, 2013).

Reuter et al. (2014) were not the first who analyzed satellite XCO2 retrievals and found a larger European carbon uptake (see references given in Reuter et al., 2014, in particular Basu et al., 2013, and Chevallier et al., 2014). However, Reuter et al. (2014) were the first who performed a very detailed analysis focusing on Europe only with the goal to find out if the previously reported findings that the satellite-derived European carbon uptake is larger than previous estimates (reported in Basu et al., 2013, and Chevallier et al., 2014) are real or an artefact. The goals of the Reuter et al., 2014, paper are therefore the same as the goals of the Feng et al. manuscript. However, Reuter et al. (2014) present a more appropriate analysis to answer the "real or artefact" question as they specifically address potential issues discussed in the literature which may result in erroneous European carbon fluxes.

To achieve this, Reuter et al. (2014) used a new CO2 flux inversion method, insensitive to potential (e.g., seasonally varying) retrieval biases, analyzed several satellite XCO2 data products, performed various sensitivity assessments and used satellite data only

over Europe to make sure that potential retrieval biases of the satellite data outside of Europe do not adversely impact the European results. The latter was in particular motivated by Chevallier et al. (2014), who argued that retrieval biases outside the region of interest may lead to errors of the derived carbon flux strength for the region of interest. In particular Chevallier et al. (2014) classified their obtained large European sink value as "artifact", e.g., for this potential reason.

Reuter et al. (2014) concluded for their ensemble analysis using Europe only data (i.e., eliminating the potentially critical error source mentioned in Chevallier et al., 2014) that the larger strength of the European carbon sink is real and not an artefact. Of course as clearly pointed out by Reuter et al. (2014) this finding is to be understood considering the reported uncertainty limit (based on comprehensive error analysis), which is not negligible (+/- 0.30 GtC/year, 1-sigma, for 2010).

So several recent inversion studies showed that the European carbon sink is estimated by roughly about 1 GtC/year when assimilating satellite data plus in situ data compared to about 0.4 GtC/year when assimilating in situ measurements only. In this context Feng et al. cite the publications of Basu et al. (2013), Chevallier et al. (2014), Reuter et al. (2014), and Deng et al. (2013; this reference is missing in the Feng. et al. reference list). The title of their manuscript implies that the manuscript can add new inside whether this is a real phenomenon or an artefact of the analyses. Especially in respect to other studies, this is not the case and the conclusions of the authors are somehow inconsistent / unclear: on the one hand side they say "could largely be explained by ..." (i.e., it could be an artefact, could = subjunctive form of can), and on the other hand they say "the remainder can be explained by..." (i.e., implying that it is an artefact as also the sentence in the Abstract on page 1991, lines 9-10). As explained (see also below), the performed analysis is not appropriate to answer the titled question in general. Any conclusions that can be drawn from the performed analyses are specific to the utilized inversion system. For example, others do not use the EnKF technique, and/or use bias correction schemes, and/or use regional inversions instead of global inversions (see cited literature).

The manuscript of Feng et al. shows that small biases have the potential to influence the used inversion system. However this is well known from several previous studies. From this, however the authors conclude that such biases indeed exist and explain the elevated European sink seen by their inversion system. This is not supported by the performed analyses. Their performed analyses are not appropriate to show that such biases are the reason for the observed sink of other inversion systems (especially if large scale or temporal biases are accounted for as done in Reuter et al., 2014).

In summary, the title is too general and the abstract and the conclusions should make clear that the manuscript only shows that sub-ppm biases have the potential to explain the elevated sink and that the performed analyses are not appropriate to doubtlessly show that such biases indeed exist and that they are the reason for the observed sink in the used or other inversion systems. The study would be better suited for publication in ACP if more general conclusions were possible. In this context, I would recommend to search for similarities in the datasets, assumptions, models, etc. used by the studies of Chevallier et al. (2014); Basu et al. (2013); Reuter et al. (2014); Deng et al. (2014); Takagi et al.(2014); Nassar et al. (2011).

I'm sorry that I cannot be more positive but due to my general comments and due to several additional major comments (see below) regarding the performed analyses and their interpretation, I recommend rejection of the manuscript as long as not all of the comments given here have been fully addressed.

Major comments:

(1) Abstract, conclusions: The main conclusions are not supported by the performed analysis (see general comments). Additionally, the results of the performed inversion studies are specific to the used inversion system (or similar systems). The results may not be valid for other systems, especially those accounting for large scale or temporal biases. This needs to be discussed in the paper and also clearly stated in the abstract.

(2) Abstract: Page 1991, line 9 (P1991 L9): "We show ..." the performed studies are not suitable to show this (see general comments).

(3) Abstract: P1991 L20: "We find that ..." the performed studies are not suitable to show this (see general comments).

(4) P1993 L8: "Consequently, there is an ongoing debate ..." :

i) Here Feng et al. imply that the presented study can make any conclusions whether the results of Reuter et al. (2014) are realistic or not. This is not the case because in contrast to the used inversion system, Reuter et al. (2014) set up an inversion system that is by design in sensitive to seasonal biases, large scale regional biases, and is less sensitive to long range transport issues. As mentioned earlier, the presented study only has the potential to conclude about the used or similar inversion systems.

ii) Please note that the results of Reuter et al. (2014) are qualitatively consistent with those of, e.g., Basu et al. (2013) and Chevallier et al. (2014). These references should also be cited in this context because the consistency among different inversion systems, bias correction schemes, satellite instruments, etc. shows how robust this signal is.

(5) HIPPO comparison (P1995 L8-11): The performed HIPPO comparison is way too superficial to conclude which fluxes are more realistic. Please discuss/consider the following:

i) Which HIPPO campaigns have been used?

ii) HIPPO measurements are mostly performed above the Pacific Ocean which requires accurate long rang transport modelling to be correct when interpreting these data via inverse modelling or performing comparisons with model simulations.

iii) The signals here are probably not very sensitive to European fluxes.

iv) A bias comparison does not say anything. One should concentrate on spatial and/or temporal patterns.

v) The HIPPO comparison should be moved to the results section.

(6) P1995 L25ff: CONTRAIL comparison:

i) I can see no reason to limit the comparison to two European airports only. Please use also the other European airports.

ii) The differences shown in Fig.2 seem to be small. Please add panels showing the difference and quantify the differences (e.g., by calculating the root mean square difference) and discuss whether the differences are significant.

iii) As long as the manuscript aims at conclusions which may have implications also for previous inversion studies of others, the validation results of the corresponding studies should also be discussed in this context. As an example, Reuter et al. (2014) finds improved agreement with independent measurements when the satellite measurements are inverted.

(7) Seasonal cycle (Fig.1, P1995 L13-24):

i) GOSAT has a poor coverage during winter, despite this, there is a large deviation between a priori and GOSAT a posteriori in winter. Why?

ii) The results of Reuter et al. (2014) suggest that the largest uptake-increment occurs during the growing season when GOSAT observation conditions are advantageous and a priori uncertainties are largest. This point should be discussed.

(8) Inconsistency with other studies (e.g., P1995 L13ff):

i) INV_ACOS and INV_UOL are GOSAT only inversions. The combined inversions result in a European sink of 0.61 GtC/year (ACOS_INS) or 0.66 GtC/year (UOL_INS). This seems to be not consistent with the results of Chevallier et al. (2014); Basu et al. (2013); Reuter et al. (2014) finding an annual sink of roughly 1 GtC/year for combined or step wise in situ plus satellite inversion.

ii) An error of $\pm$0.1GtC/year (P1991 L16, Tab.1) seams unrealistically small compared to other inversions assimilating the same/similar in situ/GOSAT datasets (e.g., Basu et al., 2013; Chevallier et al., 2014; Peters et al., 2007; Peylin et al., 2013). Why are these error estimates so much smaller than those of, e.g., CarbonTracker which bases also on EnKF? Same for most error estimates given in Tab.1.

(9) Appendix A:

i) Omit this section or discuss and interpret the results. Just mentioning that these inversions have been performed is not enough (P1997 L9-14).

ii) Scaling the a prior errors by 2/3 enhances the influence of the a priori so that you cannot compare the results with those from the other inversion set ups. Selecting the same a priori errors will result in larger European uptake. Additionally, one can expect that the uptake will still be lower than that inferred from the global GOSAT inversions because the data gets less weight due to fewer data points (expressed by the larger a posteriori errors). I expect that the resulting error bars will overlap with those from the global inversions.

(10) Observations outside Europe (P1991 L20ff, P1997 L3ff, P1998 L16): The conclusions drawn from the MOD_NOEU and MOD_ONLYEU analyses are unclear or even wrong. The statement that 50% or 80% of the signal comes from measurements outside Europe does not help to conclude if the observed GOSAT signal is real or an artefact. Due to atmospheric transport, it is clear that measurements outside Europe include information about the European carbon sink. Let us assume for a moment that GOSAT had no errors and many more measurements (so that the results are dominated by the measurements and not the a priori). The concentrations of the INV_TCCON inversion are consistent with a 0.6 GtC/year sink. This is reflected by the results of the INV_ACOS_MOD_ALL. GOSAT measurements are consistent with a 1.2 GtC/year sink. If you mix real GOSAT measurements with concentrations of the INV_TCCON it is clear that you will end up with an European flux somewhere between

0.6 and 1.2 GtC/year. The exact number depends on transport, i.e., the sensitivity of inner/outer European measurements to the European flux. If GOSAT inversions where unrealistic due to retrieval biases, I would expect a rather little probability of having inner European bias patterns being consistent with outer European bias patterns. The fact that the fluxes of the ACOS_MOD_NOEU and ACOS_MOD_ONLYEU are basically equal indicates that the inner European GOSAT information is consistent with the outer European information. This could be interpreted as indication for the GOSAT signal being real and not an artefact. This should be discussed. In this respect, see also my comments related to Appendix A (see comment (9)).

(11) P1998 L9-10: "...coarse coverage of in situ observations is unlikely..." I don't see how your study supports this hypothesis.

(12) Monthly biases: As discussed at P1997 L14-22, monthly biases can influence the derived annual fluxes.

i) For this reason Reuter et al. (2014) simultaneously fits monthly biases. They still find a European sink of 1.0 GtC/year. Their results should be discussed in this context.

ii) It should be discussed that the derived potential impact due to monthly biases is only valid for the used inversion system. Other systems may be insensitive to such biases (e.g., Reuter et al., 2014).

iii) The conclusions (P1999L17ff) imply that the GOSAT data indeed suffer from a seasonal bias explaining 0.3 GtC/year. However, the performed analyses can only conclude on the sensitivity of the used inversion system. Even though the UoL and ACOS fluxes are similar, Fig.4 does not suggest that there is a (spatial or temporal) common bias patter in the satellite retrievals.

(13) Regional inversions: P2000L13ff "Our study suggests that...": The performed analyses does not support this hypothesis. The analysis ACOS_EU and UOL_EU have an a posteriori error of $\pm$0.16 GtC/year which would be a huge uncertainty reduction over

the current IPCC estimate of about $\pm$0.4 GtC/year (Peylin et al., 2013). Additionally, the statement ignores potential advantages of regional inversions, e.g., being insensitive to retrieval biases outside Europe.

Minor comments:

(14) P1991 L4: "Recent work has shown...": This is too general. Peylin et al. (2013) shows that in situ based inversions span over a large range with values up to about 1.5 GtC/year.

(15) P1991 L6: Add "and the Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY (SCIAMACHY)".

(16) GOSAT data: The manuscript should explain why outdated data sets have been used (ACOS v3.3 and UoL FP v4.0). The most recent versions are ACOS v3.5 and UoL FP v5.1. As an example, Reuter et al. (2014) used already ACOS v3.4. (discussion paper submitted on July 23th 2014)

(17) P1991 L9: What do you mean by "mis-fitting"?

(18) P1991 L26: Add something like "for the used (or similar) inversion systems".

(19) P1992 L13: "spatial scales < O" what do you mean?

(20) P1992 L23: "Surface flux estimation algorithms are particularly sensitive to ..." This is too general because the sensitivity strongly depends on the used inversion technique and the spatial and temporal correlation length of the bias patterns. See, e.g., Bergamaschi et al. (2007); Basu et al. (2013); Reuter et al. (2014) for inversion techniques being less sensitive to specific bias patterns and Miller et al. (2007) for a discussion of spatial error correlation lengths.

(21) P1994 L19: "Including TCCON..." How large is the additional error reduction due to TCCON? Please add error estimates for the given fluxes (0.47 and 0.56 GtC/year). If it is low, the "true" European sink could be much larger than 0.56 GtC/year (assuming

TCCON is correct).

(22) INV TCCON: The "reference" inversion set-up uses in situ and TCCON measurements. Why not using an in situ only inversion as reference?

i) In this case, you could use TCCON as additional independent validation data set.

ii) TCCON may have station-to-station and/or seasonal biases of about 0.4 ppm Wunch et al. (2011).

(23) P1993 L5-L8:

i) "While the GOSAT inversions suffer from ...": Please add "larger" because in situ measurements also may have observation errors.

ii) What do you mean by aggregation errors. In the sense of Kaminski et al. (2001); Engelen et al. (2002), aggregation errors are less an issue for GOSAT because of the denser spatial sampling and the fact that seasonally no "hard constraints" are used.

(24) P1993 L26: Within the abstract you mentioned to use an EnKF now its an ETKF?

(25) P1994 L13: Please add information on the used a priori error correlations.

(26) P1997 L27: What do you mean by "control variables"? Have you added a monthly TRANSCOM wide bias to the state vector? If so have you included some month-to-month a priori error correlations?

(27) Table 1: Add a priori flux and uncertainty.

(28) Bibliography: Please check all citations. As an example, Deng et al., 2013, is missing.

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