

Dear Editor,

We have carefully responded to all the comments provided by the two anonymous reviewers and Dr. David Baker. Given the nature of the anonymous reviews we want to justify explicitly how we have addressed some of the comments.

A major reviewer comment was that our sensitivity experiments do not falsify the elevated European uptake inferred from GOSAT data. This is true, but the argument can also be reversed for the recent experiments presented by Reuter et al 2014: they do not have sufficient data to prove that the high European uptake is a real phenomenon. The major objective of our manuscript is to openly question this anomalous uptake in order to stimulate further scientific research. In our paper we provide an alternative hypothesis, supported by numerical experiments, which can also explain the anomalous uptake using space-borne data that have regional systematic bias. Currently we cannot rule out such small systematic errors with the current ground-based observation network. After carefully evaluating the reviewers' suggestions we have decided to retain our original title to emphasize that more dedicated research is required to settle this unresolved science question.

Given the reviewers' comments we have revised the paper (in the abstract and in the main text) so that our intentions and experiment results are presented in a more precise and clearer way. We have included additional calculations that illustrate difficulties associated with removing systematic bias. As such, we think the manuscript provides a fair and balanced assessment of the situation, and we anticipate that it will promote constructive scientific discussion that will eventually lead to the development of more robust observation and inversion systems.

Because the reviewers' comments are quite long, our point-to-point responses are attached as three parts.

Yours sincerely

Liang Feng and Paul Palmer

## **Response to David Baker: “Elevated uptake of CO<sub>2</sub> over Europe inferred from GOSAT XCO<sub>2</sub> retrievals: a real phenomenon or an artefact of the analysis?”**

We thank David Baker for the detailed and constructive comments. We have carefully read the comments, and make changes accordingly in the revision. Below we address all comments (marked by italics) raised by the reviewer.

*This manuscript examines the finding that annual CO<sub>2</sub> uptake across Europe is generally larger in inversions that assimilate column CO<sub>2</sub> concentrations from the GOSAT satellite than in those that do not. Specifically, as stated in the title, it hopes to determine whether this uptake is “a real phenomenon or an artefact of the analysis”. The main artefact of concern would be potential biases in the GOSAT XCO<sub>2</sub> retrievals. However, since this is a global atmospheric flux inversion, other artefacts are also possible here: how random measurement errors and transport model errors interact with seasonally-varying GOSAT data coverage and precision to give errors in the net flux for Europe. And, since we are comparing the GOSAT flux estimates to those from a reference case based on in situ and TCCON data, similar errors could occur in that reference as well. If the difference between the GOSAT estimate and the non-GOSAT reference is due mainly to errors in the reference inversion, the increased uptake due to GOSAT could be both a true phenomenon and an artefact of the analysis (since the assumption that the reference inversion is correct is no longer the case). The manuscript presents an array of inversion experiments that help clarify the differences between the inversions that use the GOSAT data and those that do not. These experiments are helpful and deserve to be published, to help others interpret their own GOSAT analyses. However, the authors do not seem to have accomplished their goal of determining whether the increased uptake due to the GOSAT data is driving the flux estimate closer to the real fluxes or not. That question is best answered by comparing the modeled concentration results with and without the GOSAT data to independent data, and the authors do do that; however, the two CONTRAIL profiles over Europe examined here do not provide a clear answer, in my view. For publication in ACP, I think the authors must either a) compare to more independent data and show clearly that bringing in the GOSAT data does or does not improve the fit to the independent data, or b) back off from the assertions in the abstract and conclusions that GOSAT biases are responsible for the difference, and that the increased uptake is not real. In either case, the experiments here showing the impact of the GOSAT data (the change from not using it) are helpful and ought to be published — it is the conclusions taken from these experiments that must be reworked.*

The aim of this paper is to question whether the elevated European uptake inferred from GOSAT data is real or an artefact, because small biases are shown to be able to distort our interpretation of X<sub>CO<sub>2</sub></sub> retrievals. We agree that without further comparison with independent observations, we cannot rule out other possible causes, and further, determine whether elevated European uptake is real phenomenon or not. The same argument can be made for Reuter et al. We have revised the abstract and conclusions following David’s and other reviewers’ suggestions. Particularly, we state in the concluding remarks:

‘Complicated interactions between observations and the assimilation system also mean that our present study does not exclude other possible causes for the elevated European uptake reported by previous research from assimilation of GOSAT data. Instead, it highlights the adverse effects of uncharacterized regional biases in current GOSAT X<sub>CO<sub>2</sub></sub> retrievals that can attract erroneous interpretation of resulting regional flux estimates. A more thorough evaluation of the X<sub>CO<sub>2</sub></sub> retrievals using independent and sufficiently accurate/precise observations is urgently required to increase the confidence of regional CO<sub>2</sub> flux estimates inferred from space-based observations...’

*...Given that, it is not clear to me that the CONTRAIL data at these two airports really help determine whether the GOSAT data improves or worsen the estimate of the European sink. There is a good bit of other data in Europe that could be used to examine this question, though: other aircraft profiles, mountain-top data, and the European TCCON sites, if they could be left out of the reference inversion and used for the independent comparisons. A more broad-based effort to compare to high-quality, independent data is needed to be able to say whether the increased uptake due to GOSAT is incorrect or not.*

We agree that due to model error, unaccounted local sources, and limited model resolution etc., the results from our numerical experiments and the corresponding comparisons with CONTRAIL ascent and descent mole fraction data are not very impressive (lower by 0.5-1.0 ppm during the boreal summer). However, the model is able to capture the observed seasonal cycle and the correlation is reasonable (>0.7). As pointed out

by the reviewer, the main aim of the comparison is just to show that assimilation of GOSAT  $X_{CO_2}$  outside Europe leads to a higher  $CO_2$  inflow into the European region at the beginning of 2010. Higher  $CO_2$  inflow can, in turn, induce an enhanced European uptake estimate, even when  $X_{CO_2}$  data within Europe are not biased themselves. Generally, in-situ only inversions show better agreement with independent aircraft observations than the GOSAT only inversions (Houweling et al., 2015). However, due to limited observational coverage, and unquantified transport errors etc., current model-observation inter-comparisons themselves are not sufficient to discard either GOSAT only or in-situ only inversions.

*'...Given this non-local link between fluxes and measurements taken far away, it might be worth doing some additional sensitivity experiments to investigate the impact of including M-gain measurements over land and glint-mode measurements over the oceans. Is the increased sink over Europe still obtained in that case? Is it larger or smaller?'*

This is a good suggestion. We do not use M-gain or glint observation due to data providers' suggestion or due to the availability of that data (e.g. no glint data for UoL v4). We will include them in our future experiments when we assimilate newer versions of GOSAT data.

*'...Why that is the case is not entirely clear. Is it because the in situ + TCCON data are given much greater weight in the inversion than the GOSAT data (both in terms of precision and number of data points)? Or is it because the inversion finds it easier to resolve differences between the in situ/TCCON data and the GOSAT data by solving for a measurement bias in place of a flux correction? To resolve the issue of the relative weight in the inversion, it would have been useful for the authors to have included the intermediate case: inverting for both the GOSAT and in situ/TCCON data together without solving for the  $X_{CO_2}$  biases. And what does it mean to solve for measurement biases as part of the flux inversion, in the first place? The bias corrections made to the data by the retrieval teams (ACOS and UOL) have used the best available validation data already (TCCON, suites of models). The bias estimates done as part of the atmospheric inversion are then seeking improve the retrieval teams' best bias estimates through comparison to the a priori  $CO_2$  fields given by the particular models used here: this rolls together the effects of errors in the prior fluxes and transport model, and can lead to  $X_{CO_2}$  bias corrections that may have little to do with actual measurement issues. That being said, the biases that are estimated in this approach do seem to have large negative values for Feb-Apr, on the order of 0.5 ppm, at least in Western Europe for the ACOS case. If these bias estimates are correct, they might explain 0.18 GtC a<sup>-1</sup> of the larger GOSAT uptake, according to the authors.'*

As pointed out by the reviewer, the actual results depend on relative weights given to each type of observations, as well as on the assumed uncertainties for prior flux and bias estimates. More strictly speaking, the derived biases are the systematic differences between model and GOSAT  $X_{CO_2}$  retrievals. So in the revision, we have discussed limitations of the joint data assimilations. Also, a further test shows that when no bias correction is used, the uptake inferred by the joint data assimilation experiment INV\_ACOS\_INS will be increased from 0.62 GtC/a to 0.77 GtC/a (see Section 4). But the most important point is: we infer an European uptake around 0.62 GtC/a by jointly assimilating GOSAT and in situ observations together with a simple bias correction scheme. Those derived monthly biases are varying, and mostly within 0.5 ppm, which is a challenge to study based on the current validation network.

*'...For example, did they correct the  $X_{CO_2}$  data with all 12 of the regional biases estimated in the INV\_ACOS\_INS and INV\_UOL\_INS cases, or just the ones for Western and Eastern Europe?'*

Only the biases over West and East Europe have been corrected. We have clarified this point in the revised manuscript.

*I found these sensitivity experiments helpful for understanding the European sink obtained in the authors' global GOSAT flux inversion results, but I often didn't agree with their interpretation of the experiments and the terminology they used. In the Abstract, they say "We show this elevated uptake over Europe could largely be explained by mis-fitting data due to regional biases." Biases in what, the  $X_{CO_2}$  measurements? Yes, regional  $X_{CO_2}$  biases might explain the difference, but that is not the only possible explanation: the fluxes in the in situ + TCCON inversion might be biased over Europe due to the amplification of measurements errors caused by the sparse spatial density of the measurements, because of errors in representing the in situ data with coarse resolution models, or due to biases in the TCCON data, for*

*example ...'*

The main aim of this paper is to stress that currently we are not certain whether the elevated European uptake is real or an artefact. We show this by highlighting the sensitivity of the flux estimates to possible regional biases within or outside Europe. We totally agree that there are other possible explanations and causes for the elevated uptake as well. We only suggest that regional biases can result in such elevated uptake (while current observation network cannot rule out these small and varying biases). We have rewritten the introduction and conclusion to make these points clearer.

*'At the end of the Abstract, "We find a monthly varying bias of up to 0.5 ppm can explain an overestimate of the annual sink of up to 0.18 GtC a<sup>-1</sup>" — again, the implication is that the large European uptake from the GOSAT data is wrong and that lower uptake from in situ +TCCON data is right. The same point (that the difference could be due to XCO<sub>2</sub> biases) could be made using language that doesn't try to argue which estimate is more correct. "Overestimate" could be changed to "larger value", etc. In the "Discussion and Conclusions", the influence of GOSAT measurements outside of Europe on European net fluxes is described as "...a positive model bias of CO<sub>2</sub> being transported into Europe, due to the assimilation of GOSAT XCO<sub>2</sub> data outside of Europe" and an "elevated CO<sub>2</sub> inflow into the European domain". The effect of biased "boundary conditions" and "model inflow" are mentioned, as if a regional inversion is being used. Rather than using this language, perhaps it would be easier just to note that the GOSAT data tend to drive larger uptake in Europe balanced by less uptake in the same northern latitudes outside of Europe, with corresponding lower and higher CO<sub>2</sub> concentrations over each area? "Erroneous interpretation of XCO<sub>2</sub> data can result from analyses if unbiased boundary conditions are not addressed": while this is not completely clear to me, it sounds like the authors are saying that biases in the GOSAT XCO<sub>2</sub> data are responsible for the increased uptake, and this has not been established.*

See above responses. Both our global and regional inversions in Appendix A suggest that boundary conditions produced by assimilating GOSAT XCO<sub>2</sub> retrievals outside EU will result in significantly enhanced European uptakes, particularly at the beginning of 2010. We agree that because of limited observation coverage and unquantified model transport errors etc., we cannot conclude that GOSAT XCO<sub>2</sub> retrievals themselves are biased high or low. It is actually one of our major points that there are not sufficient independent observations to falsify the in situ only inversion or the GOSAT only inversion. We have stressed this in the main text and in the concluding remarks.

*In the third paragraph of the "Discussion and Conclusions", I agree with discussion of the estimated XCO<sub>2</sub> biases, but I would welcome some more discussion about what a correction to the bias corrections already solved for and removed by the retrieval teams actually means. What is the motivation for it, why is inverting for it as part of the atmospheric inversion possible, what are some of the potential pitfalls?'*

The retrieval teams mostly used co-located TCCON and GOSAT observations to derive bias correlation. Our bias correction scheme is based on the (on-line) comparisons between model simulation and GOSAT retrievals, which are able to take into account more GOSAT retrievals to infer monthly biases at regional scale. In addition to the TCCON network, the joint assimilations have also used conventional surface observations, and the GOSAT XCO<sub>2</sub> data themselves. But there are issues with on-line bias correction schemes, particularly before we are able to properly characterize systematic observation and model errors. In revision, we added discussions on those potential issues in both Section 4 and Appendix A.

*In the final paragraph, I agree with the authors that "This study highlights the adverse effects of regional biases in current GOSAT XCO<sub>2</sub> retrievals that can attract erroneous interpretation of resulting regional flux estimates." However, the way it is written implies that such biases are responsible for the increased uptake when GOSAT data are added to the inversions, and this has not been demonstrated convincingly. Coming where it is at the end of the conclusions, it appears to be answering the question asked in the title: "...is [the increased uptake in Europe] a real phenomenon or an artefact?". If the authors wish to retain this language and implied conclusion, they must bring in additional independent data and show more convincingly that the increased uptake due to GOSAT data worsens to fit to them. If they do not want to take that approach, they should reword the interpretation and conclusions to discuss the shift towards greater uptake, without judging if it reflects reality or not'*

We have clarified these points in the revised manuscript to make it clear that while we study the impact of uncharacterized biases on the elevated European uptake there are other possible explanations including that the signal is real (See above responses, and the revised concluding remarks). Our results just stress that more dedicated measurements are required to determine whether the elevated European uptake is real or not.

*‘Overall, I think the authors have done a nice job on this paper, but they just need to be a bit more careful with their conclusions, explicit or implied. It would be nice if they could show more conclusively that the larger net uptake over Europe is inconsistent with independent data. If that is not possible, a careful rewording of the title, abstract, and conclusions is needed that retains the main thrust of the sensitivity experiments without asserting too much.’*

We thank David for this measured assessment of our work. His recommendations together with other reviewer comments have helped us to revise the manuscript.

**Some more detailed comments follow:**

*1. page 1994, line 12: “and the annual variations”: It is not clear what field with inter-annual variations you are referring to here — land biosphere? Land + ocean + fossil fuel + biomass burning? Please clarify.*

We have rewritten the paragraph in section 2 to provide more details about our a priori error covariance.

*2. p 1994, L 13: The global CO<sub>2</sub> fluxes often have large temporal and spatial correlations, such that the global uncertainty from an inversion may be small, while at the same time smaller-scale flux uncertainty can be quite large. Do you account for any such correlations in doing the global uncertainty scaling mentioned here? What is the percent uncertainty on the land biospheric fluxes after this global scaling? (That is, how different is it from the initial 70% that you mention?)*

Following our previous study (see Chevallier et al., 2014), we have included a spatial error correlation with a correlation length of 800km for land, and 1500 km for ocean in our prior errors. We have also included a temporal correlation with a correlation length of 1 month. The rescaling is applied to aggregated annual global land and ocean errors after taking into account these correlations. We have added this information in the revised manuscript (see above response).

*3. p 1995 L 8-11: for comparison, please also give the bias with respect to the HIPPO measurements given by the INV\_TCCON case — how much better was it in that case, globally?*

For INV\_TCCON, the bias against HIPPO-3 is about 0.05 pm. We have added this information (and new figure 2) in the revised manuscript.

*4. p 1995 L 15: Judging from Figure 1, it would seem you are discussing the results for June 2010 rather than July.*

Thanks for spotting this mistake. Yes, it is for June. We have corrected this mistake in the revised manuscript.

*5. p 1995 L 18-24: This point that the GOSAT-only inversions result in the largest uptake compared to the in situ/TCCON case in early Spring / Winter is important — it contradicts the idea that the GOSAT data cannot drive large changes from the prior in winter when coverage at high latitudes is poor.*

This is an interesting result. Such large uptake is also found in experiments by Chevallier et al., using a variational approach.

*6. p 1996 L 13-15: “...indicating an overestimate in the CO<sub>2</sub> transported into the European region in GOSAT inversions. This highlights the sensitivity of the European flux estimate to lateral boundary conditions.” Another way of saying this is that large deviations of flux in Europe in the inversions tend to be anti-correlated with flux deviations outside of Europe at similar northern latitudes. This is a consequence,*

*apparently, of the a posteriori flux uncertainties still being rather high at the scale of large regions like Europe in the GOSAT inversions.*

We agree, and modification is made to stress that at that season, Europe is poorly constrained.

7. p 1996 L 24: *replace “with a model” with “with those from a model”*

Change made following the suggestion.

8. *End of p 1996, beginning of p 1997: You seem to be discussing results shown in Figure3, but you do not mention that figure here. Maybe mention Figure 3 here?*

The corresponding figure has now been mentioned.

9. p 1997 L 16: *Consider replacing “we add 0.5 ppm” with “we add a bias of +0.5 ppm”. When I first read this, it was not clear to me whether you were adding a bias to the data, or increasing the assumed measurement uncertainty by 0.5 ppm.*

Change is made to clearly say that a bias of + 0.5 ppm has been added.

10. p 1997 L 24: *“...to quantify systematic bias” — bias in what? Fluxes or measurements?*

We change the phrase to: to estimate systematic bias in XCO<sub>2</sub> retrievals.

11. p 1997 L 24: *“online”: It is not at all clear what you mean by this here. With some work the reader eventually will piece together what you mean, but maybe you can reword things a bit to make it easier. “On-line” = solving for biases as part of the inversion; “off-line”=deducing biases via comparisons of a posteriori modeled CO<sub>2</sub> fields and XCO<sub>2</sub> data.*

Thank for suggestions. We have revised the Section 4 to clarify the meaning of ‘on-line’, where observation biases are estimated together with regional fluxes from joint assimilation of GOSAT and in situ observations.

12. p 1998 L 3-4: *“the main advantage of our online bias estimation is that the uncertainties associated with errors in flux estimates can be taken into account.” In what, the bias estimation procedure? Does “uncertainties” refer to the bias estimate? Or the flux estimate? Please reword for clarity.*

It is for the uncertainty in model CO<sub>2</sub> concentrations caused by errors in flux estimates. We have rewritten the paragraph in the revision.

13. p 1998 L 4-5: *“To investigate the spatial pattern of the XCO<sub>2</sub> biases within Europe, we split Europe into West Europe...” This is for the purposes of solving for the measurement biases, right? Maybe say so more explicitly.*

Changes made to clarify that we are solving for sub-region observation biases.

14. p 1998 L 8-9: *Please put minus signs on the European flux values — you don’t refer to them as “uptakes”, but rather “fluxes”, so we need the sign.*

We agree, and change them to ‘European uptake’ to avoid confusion.

15. p 1998 L 15-16: *“...We find that after correcting for these biases the annual European uptake estimate from INV\_ACOS is reduced by 0.18 GtC a<sup>-1</sup>”: It is not clear where you got this 0.18 GtC a<sup>-1</sup> figure from. If I take the difference of the values for the INV\_ACOS\_INS and INV\_ACOS cases from Table 1, I get: -0.61 - (-1.20)=+0.59. Is this correction for the biases done with some additional inversion or forward run not*

mentioned in Table 1? Or are the values in Table 1 for the INV\_ACOS\_INS case done without the biases being estimated in the state (in addition to the fluxes)?

Yes, we have made an extra GOSAT inversion experiment after the derived  $X_{CO_2}$  biases over West and East Europe were corrected. This is described in the revised manuscript.

*16. p 1999 L 4-5: "...is determined by a positive model bias of CO2 being transported into Europe": This language doesn't help clarify the experiments, in my opinion. What the experiments show is that inversion of GOSAT data outside of Europe cause large uptake in Europe counterbalanced by a decreased uptake outside of Europe. I don't think "bias" or "transport" need to be brought up to make this point.*

To make this point clearer, we have included extra experiments in Appendix A. We found similar enhanced uptake at the beginning of 2010, when a posteriori fluxes from GOSAT inversion INV\_ACOS are used to produce the boundary conditions for quasi-regional inversions, where only ACOS observations within Europe are assimilated. So we change the sentence as:

'... appears to be related to the systematically higher model CO<sub>2</sub> mass being transported into Europe, due to the assimilation of GOSAT  $X_{CO_2}$  data outside the European region.'

## **Response to reviewer two: “Elevated uptake of CO<sub>2</sub> over Europe inferred from GOSAT X<sub>CO2</sub> retrievals: a real phenomenon or an artefact of the analysis?”**

We thank the anonymous reviewer’s comments, which help us improve our manuscript. We have carefully read the reviewer’s comments, and make changes in the revision accordingly. Below we address all comments (marked by italics) raised by the reviewer.

*After Reuter et al. (2014), Feng et al. specifically address the current inconsistency between satellite-based atmospheric inversions and other sources of information about Europe’s carbon sink. Both studies present a series of sensitivity tests (some tests being rather similar between the two), but they come to a different conclusion. The reason for the divergence is not made explicit, which is all the more surprising that four scientists (half of the current team) co-author both papers.*

In this paper, we propose a different hypothesis on the elevated European uptake inferred from GOSAT X<sub>CO2</sub>. We have investigated the relationships between flux estimates and possible observation biases within and outside European region. Our global (and quasi-regional) inversion experiments shows that a large portion of the enlarged European uptake is related to elevated CO<sub>2</sub> inflow caused by assimilating GOSAT X<sub>CO2</sub> retrievals outside the immediate European region. A varying sub-regional bias of 0.5 ppm can explain much of the remaining extra uptake. Currently there are no sufficient data to rule out that GOSAT X<sub>CO2</sub> retrievals are indeed biased.

There are many differences between the regional flux inversions used by Reuter et al., and our global inversion approach. Several previous reports of elevated Europe uptake (such as Deng et al., (2014); Basu et al., (2014), and Chevallier et al., 2014) are also based on global flux inversion systems. Using our global inversion system, we are able to show that GOSAT X<sub>CO2</sub> data outside Europe can have significant impact on the European flux estimate. Another important difference is how to use regional bias correction. As discussed in our revised Appendix A, applying on-line bias correction is helpful, particularly for limiting the adverse effect from inaccurate boundary conditions around Europe. However, characterizing and correcting for systematic bias is non-trivial. Mis-characterization tends to weaken observational constraints and compromise a posteriori flux estimates.

Finally, this paper is not intended to invalidate the work by Reuter et al. Instead, it highlights that without extra measurements, we cannot reach a robust conclusion about whether the elevated uptake was a true phenomenon or an artefact caused by uncharacterized systematic bias of the data or associated with issues of inversion approach. That is the reason all the co-authors are supporting for further investigation on this topics.

*The heart of the present study seems to lie in the short fourth section (“Bias estimation”) that clearly contradicts Reuter et al.: it would deserve more substance. For instance, can the authors demonstrate the superiority of INV\_ACOS\_INS and INV\_UOL\_INS compared to the others are the inferred retrieval biases consistent with misfits to TCCON; can the inferred biases be linked to physical variables? I note that the correction to the West-East retrieval gradient reaches nearly 1 ppm during some months, which is considerable.*

The joint data assimilations INV\_ACOS\_INS and INV\_UOL\_INS are part of our experiment set to show that flux inversions are sensitive to small regional biases, which, currently, cannot be properly characterized by independent observation network. INV\_ACOS\_INS and INV\_UOL\_INS are able to explore larger constraints from both in-situ and space-based observations, which coverages are often complementary to each other. Including an online bias correction also helps to (partially) remove possible biases in X<sub>CO2</sub> retrievals, provided they are consistent with the assumed spatial and temporal patterns. INV\_ACOS\_INS and INV\_UOL\_INS have much (~60%) less European uptake than GOSAT only inversions. Also, a posteriori model concentrations for INV\_ACOS\_INS and INV\_UOL\_INS agree better with independent aircraft observations than the GOSAT-only inversions. But we agree that there are no sufficient observations to fully prove (or disprove) the results, including the bias estimates as well as the small European uptake around 0.6 GtC/a. So they are indeed part of our main argument that whether the elevated European uptake is an artefact or a real result is a question that demands further investigation.



*In summary, I would therefore only recommend publication if an extra depth of analysis is provided that clearly shows the added value of the new sensitivity tests and justifies the change of conclusion.*

As stated in above responses, the emphasis of our paper is that observation biases can result in an apparent elevated estimate of European uptake, and as shown in the revised Appendix, we have no robust approach to remove adverse effects of the uncharacterised observation biases. So we believe this manuscript raises a valid question on whether the elevated European uptake inferred from GOSAT data is real or an artefact due to the high sensitivity of flux estimates to small regional biases, which cannot be ruled out without further dedicated measurements.

#### **Detailed comment:**

*1) Abstract and introduction: the text suggests that current knowledge about regional carbon fluxes comes from atmospheric inversions, but actually most of it comes from process models, flux measurements and inventories.*

We agree with the reviewer. To avoid such impression, we have changed the sentence in introduction to ‘the top-down flux estimates have not improved...’

*2) As shown throughout the text, the inversion uncertainties are unrealistically small. Does this come from a flaw in their computation or from a flaw in the inversion configuration? Less striking, the prior global uncertainty seems to be quite small (p.1994, l.13) given the type of prior fluxes used. Last, as it is presented, the sensitivity test about the prior uncertainty suggests that the uncertainty about the prior error covariance matrix drives the satellite-based inversion, leaving not much value to the other sensitivity tests, hence to a large part of the paper.*

We thank the reviewer spotting this mistake. We mistakenly replaced the unit convert factor of 144 (=12x12) with 199 the number of geographical regions. We have corrected this error, and also increase the apriori uncertainty by 20% in the revised calculation. The resulting a priori uncertainty for our monthly European fluxes varies from 2 GtC/a for summer months to 0.8 GtC/a for winter months, which is generally larger than that used by Deng et al. (2014). As shown in the revised Table 1, for GOSAT-only inversions (INV\_ACOS and INV\_UOL), the 20% increase of the a priori uncertainty has resulted in about 15% more European uptake. But these increases do not change (and in fact even enhance) our main conclusion about the high sensitivity of the flux estimate to regional or sub-regional observation biases. In addition, we have further tested our main results by doubling a priori uncertainty (e.g., the INV\_ACOS\_DBL\_ERR and INV\_ACOS\_INS\_DBL\_ERR in Table 1). We also add one sentence to point out that a posteriori uncertainty can be underestimated by the inversion system itself:

‘However considering the limited spatial resolution (only 12 sub regions for the whole TransCom European region), and unquantified model transport and representation errors, we anticipate that the complete a posteriori uncertainty is larger than the value estimated by the inversion system itself, as suggested by large inter-model variations found for in situ inversions [e.g., Peylin et al., 2013].

*3) p.1994, l.15: this is minor, but the reader may wonder why in situ (continuous) measurements are discarded.*

We indeed have used some continuous measurements as well. To avoid confusion, we have changed it to ‘conventional surface observation’.

*4) p.1994, l.16: GGG2012 had known problems that can be damped at least with the recommended bias correction ([https://tcccon-wiki.caltech.edu/Network\\_Policy/Data\\_Use\\_Policy/Data\\_Description\\_GGG2012#Laser\\_Sampling\\_Errors](https://tcccon-wiki.caltech.edu/Network_Policy/Data_Use_Policy/Data_Description_GGG2012#Laser_Sampling_Errors)) but the authors seem not to have used it.*

When our major calculations were made, bias corrections for several European TCCON sites were not available, so we chose to use GGG2012 to avoid possible inconsistency. We have now re-calculated our

results using the GGG2014 data.

5) *The comparison to HIPPO would deserve more details, or it should be removed.*

A revised Figure 2 shows that GOSAT-only inversions generate higher concentrations over low latitudes.

6) *p.1998, l.9-11: it is not clear how the authors come to this conclusion.*

What we mean is that: although in the combined inversions INV\_ACOS\_INS and INV\_UOL\_INS we have assimilated the GOSAT XCO<sub>2</sub> over east Europe, the annual net European uptake is close to the in-situ only inversions. But we agree that the impact of observations over East Europe needs further investigation, so we drop this sentence.

7) *p.1998, l.19-21: the role of this sentence in the logic is not clear.*

We change the sentence as:

‘The effect of bias correction is much smaller for INV\_UOL (0.07 GtC/a), because of the different bias patterns.’

## **Response to reviewer one: “Elevated uptake of CO<sub>2</sub> over Europe inferred from GOSAT XCO<sub>2</sub> retrievals: a real phenomenon or an artefact of the analysis?”**

We'd like to thank the reviewer's detailed comments, which indeed have helped us improve our manuscript. Below we address all comments (marked by italics) raised by the reviewer.

### **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 shown below the analysis performed by Feng et al. is not appropriate to validate or invalidate the results presented in Reuter et al. (2014)”*

The title of the paper was chosen intentionally to highlight that we had not reached a robust conclusion about whether the elevated European uptake reported by previous researches was a true phenomenon or an artefact caused by uncharacterized systematic bias of the data or associated with issues of inversion approach. As noted by the reviewer many previous studies, including ours, reported a large European carbon uptake during summer inferred from GOSAT data (e.g., Basu et al., 2014, Deng et al., 2014, Frederic et al., 2014), but Reuter et al (2014) was the first one to highlight this result as a real phenomenon. Reuter et al might well be correct that this is a real phenomenon and Europe is indeed taking up more carbon than previously thought, but we have proposed an alternative hypothesis involving systematic bias of data within and outside the European region. The artefact in this case is the mis-interpretation of the data if they have uncharacterized biases. Currently there are no sufficient data to rule out that GOSAT X<sub>CO<sub>2</sub></sub> retrievals are indeed biased. Also as shown in revised Appendix A, characterizing and correcting for systematic bias is non-trivial. Mis-characterization tends to weaken observational constraints and compromise a posteriori flux estimates.

Our objective was not to invalidate the work by Reuter et al., but to highlight that other hypotheses are consistent with available data as well. Our intention was to promote further studies in this area. In the revised abstract, we make this point clearer.

*Feng et al. 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.*

The aim of this paper is to question whether the elevated European uptake inferred from GOSAT data is real or an artefact due to the high sensitivity of flux estimates to small regional biases. We have investigated the relationships between flux estimates and possible biases within and outside European region. Our global (and quasi-regional) inversion experiments shows that a large portion of the enlarged European uptake is related to elevated CO<sub>2</sub> inflow caused by assimilating GOSAT XCO<sub>2</sub> retrievals outside the immediate European region. A varying sub-regional bias of 0.5 ppm can explain much of the remaining extra uptake. We do not have a sufficient number of independent observations to preclude the possibility of such regional observation

biases. Also, we show it is non-trivial to develop a robust inversion system to detect and correct these biases. These points have been stressed in the revised manuscript.

*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 CO<sub>2</sub> (Reuter et al., 2014) reflects a real phenomenon or is an artefact of uncharacterized regional biases”.*

See above for the explanation why we highlight Reuter et al. We fully acknowledge other previous studies that report similar results.

*Reuter et al. (2014) were not the first who analyzed satellite XCO<sub>2</sub> 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)... 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.*

We agree that the two papers have similar objectives. The emphasis of our paper is that observation biases can result in an apparent elevated estimate of European uptake, which cannot be ruled out without further dedicated measurements. Similarly, more measurements are needed to invalidate the hypothesis by Reuter et al.

*To achieve this, Reuter et al. (2014) used a new CO<sub>2</sub> flux inversion method, insensitive to potential (e.g., seasonally varying) retrieval biases, analyzed several satellite XCO<sub>2</sub> 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. [...text with no questions...]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.*

*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.*

The title was just chosen to emphasize that there is no consensus about the elevated European uptake of CO<sub>2</sub>. As stated above as well as in our revised concluding remarks, our work *does not* invalidate the science reported in Reuter et al. The results we reported *are* general: even a small systematic bias can compromise interpretation of observations.

It is difficult to develop a robust way to remove the adverse impacts of uncharacterised observation biases. We have previously applied bias corrections to GOSAT XCH<sub>4</sub> inversions (Fraser et al., 2013, 2014), and XCO<sub>2</sub> inversions (Feng et al., 2014, IWGGMS). From these studies, we have learned the limitations of the so-called on-line bias correction: 1) unintentionally removing the real signal of the varying surface fluxes, and 2) the method only being effective when the observation biases actually appear as the assumed patterns. An important question about the regional inversions with on-line bias correction is how to specify the bias pattern and its prior uncertainty. As shown in Appendix A, if a priori uncertainty of the bias is too large we may weaken the observational constraint of the varying monthly mean concentration on the biosphere seasonable cycle across the region, so that we are unable to establish a steady relation between the inferred fluxes and the ‘true’ regional total. We have detailed this discussion in Appendix A.

#### **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.*

See above responses to general comments. Our results highlight the sensitivity to (sub-) regional observation bias within and outside Europe. We also show that it is difficult to develop a robust bias correction scheme before the systematic errors with both the observations and models have been properly characterized. Instead, using different observations under different assumptions, we are able to infer quite different European uptakes, which cannot be invalidated by currently available observations. So it is reasonable for us to question whether the elevated European uptake inferred from GOSAT data is real or an artefact due to small regional or sub-regional biases.

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

Please see our response above.

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

Please see our response above.

*(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.*

Our paper suggests a different explanation for the elevated European uptake inferred from the GOSAT XCO<sub>2</sub> data, which can be not ruled out by the current observation network. Please see our response above about the impact of regional bias on our global and quasi-regional inversions.

*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.*

Our GOSAT-only inversions (which earlier results are included in Chevallier et al (2014)) also show a similar enhanced uptake over Europe. Here, we just put forward an explanation of this result.

*(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?*

We use HIPPO-3 from 2010. We have clarified this in the revised manuscript.

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

We agree that (in-)validating flux inversions need to consider transport errors, representation errors, etc. Here, our comparisons are used to show that GOSAT-only inversions generate higher a posteriori model concentrations over lower latitudes than the in-situ only inversions. These higher concentrations are not supported by HIPPO observations. We have stressed this in Section 2 as well as in our concluding remarks.

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

The comparison is not about the observation signals to constrain European fluxes directly. Together with the comparison with CONTRAIL data over Europe, it just shows that in the air mass inflow to Europe, CO<sub>2</sub> concentrations from GOSAT-only inversions are higher than that from in situ inversions, and they are also higher than independent HIPPO-3 observations at middle and low latitudes. When CO<sub>2</sub> in air inflow is overestimated, the mass balance will dictate an elevated European uptake, even when GOSAT XCO<sub>2</sub> retrievals within Europe are not biased themselves. This point is made more clearly by additional quasi-regional inversions presented in Appendix A.

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

We have added a new Figure (Figure 2) to the revised manuscript, which shows that GOSAT-only

inversions overestimate the concentrations over low latitudes.

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

As mentioned above, the comparison with HIPPO is not included as an evaluation of our inversions but as a background for the following study focused on European region.

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.*

In 2010, these are only descending and ascending CONTRAIL data available for airports in Europe.

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.*

The purpose of this Figure is to show that CO<sub>2</sub> mole fraction data corresponding to fluxes inferred from GOSAT data are higher than those inferred from in situ data at the beginning of 2010. We are happy to show this comparison as differences instead of absolute amounts. But considering that the agreement with aircraft data is affected by many other factors such as model transport and representation errors, and unaccounted small-scale local sources etc., it does not invalidate flux estimates directly. We have stressed this point in Section 3.

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.*

Recent inter-comparisons of 8 different inversion systems by Houweling et al. (accepted for publication in *J. Geophys. Res.*), which also include our earlier results, show that a posteriori model concentrations inferred from GOSAT X<sub>CO<sub>2</sub></sub> data generally have worse agreement with independent aircraft observations than those inferred from in situ data. Some inversions based on GOSAT data have shown better agreement with TCCON network, partially because TCCON network has been used by several retrieval groups to correct GOSAT X<sub>CO<sub>2</sub></sub> biases. In the present study, we have already included TCCON data into the reference inversion to improve the agreement with TCCON network. However as mentioned by the reviewer, considering unaccounted model errors and limited observation coverage, worse agreement with currently available observations does not necessarily falsify GOSAT data in favour of the in situ data. Our concluding remarks stress this point.

(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?*

First, GOSAT has a few observations over the Southwest part of Europe. More importantly, different from Reuter et al., we have used a 5-month assimilation window, so that observation made in late Spring and early Summer were also used to constraint flux estimates during winter months.

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.*

As discussed in the manuscript, our inversion using in situ data already has a large summertime uptake due to the use of TCCON data. The size of this summertime uptake peak agrees well with

previously reported GOSAT inversions from our own and other groups (including Reuter's peak values).

*(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.*

When combining data from different sources, the flux estimates obviously depend on the relative weights given to the in situ and GOSAT data. This point has been included in Section 4. In fact, smaller European uptake estimates have been found in several experiments when assimilating GOSAT XCO<sub>2</sub> and in situ observations together (see Houweling et al., 2015). Also, we have included TCCON observations as additional in situ observations, and introduced bias corrections to GOSAT XCO<sub>2</sub> retrievals. As a result, we anticipate a strong influence by in situ observations where they are available. Reuter et al. used a quite different approach.

*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.*

We thank the reviewer for spotting this mistake. We mistakenly replaced the unit convert factor of 144 (=12x12) with 199 the number of geographical regions. In the revised calculations, we also increased the a priori uncertainty by 20%. The resulting a posteriori uncertainty for ACOS inversion is now 0.19 GtC/a, which is close to 0.23 Gt/Yr by Chevallier et al (2014) who has used a variational data assimilation system. More importantly, in the revision, we have stated:

‘However considering the limited spatial resolution (only 12 sub regions for the whole TransCom European region), and unquantified model transport and representation errors, we anticipate that the complete a posteriori uncertainty is larger than the value estimated by the inversion system itself , as suggested by large inter-model variations found for in situ inversions (e.g., Peylin et al., 2013)’

(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).*

We decided that the core message should be contained in the main text while the important details about quasi-regional inversions should be kept in the Appendix to improve the overall readability of the main text. We have also rewritten Appendix A so that it is more focused on the effect of the boundary conditions as well as the on-line bias correction with a large a priori uncertainty.

*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.*

We apply the factor of 2/3 to reflect the a priori is taken from the a posteriori fluxes from INV\_TCCON. We have stressed this point in the revision. Also, using an alternative factor of 1, for example, increasing the uptake by 0.08 GtC/a, which does not change our discussions significantly.

*(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 inner/outer European measurements to the European flux. If GOSAT inversions were 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)).*

We respectively disagree with the reviewer. The monthly fluxes inferred in ACOS\_MOD\_NOEU and ACOS\_MOD\_ONLYEU are actually quite different from each other: ACOS\_MOD\_NOEU shows much larger uptake at the beginning of 2010, while ACOS\_MOD\_EU has a larger uptake during the summer. The resulting annual net uptake is just a coincidence, which has not been shown in results for another (UOL) GOSAT data set.

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

We mean that even including the GOSAT observations over eastern Europe, the joint data inversion is not far from the in situ inversion, particularly after the on-line bias correction. But we agree that the contribution from observations over East Europe need further quantification in the future. So we have removed this sentence.

*(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*

First, the ultimate aim of this paper is *not* to directly invalidate results described by Reuter et al.

*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).*

As discussed in above responses, this study provides another hypothesis on why global flux inversions infer much larger European uptake from GOSAT  $X_{CO_2}$  retrievals, and such hypothesis cannot be ruled out by current observation network. But we agree that different systems may have different sensitivity to certain biases we presented here. So in the concluding remark, we added:

‘Complicated interaction between observation and the assimilation system means that our present study does not exclude other possible causes for the elevated European uptake reported by previous researches from assimilation of GOSAT data. Instead, it highlights the adverse effects of uncharacterized regional biases in current GOSAT  $X_{CO_2}$  retrievals that can attract erroneous interpretation of resulting regional flux estimates...’

*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 patten in the satellite retrievals.*

That is true for the West European region. However, there appears to be a generally positive bias over the tropics (Figure 2), which, unfortunately, cannot be directly confirmed by using current TCCON network. Interestingly, when we remove the impact of GOSAT data outside the European regions, the inversion based on UoL v4 data has a net European uptake very close to that inferred from the in situ data. This is one of the results that motivated us to write this manuscript.

*(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 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.*

We agree that the a posteriori uncertainty from inversions tend to be underestimated by the inversion system itself, which is stressed in the revision (Section 2). We also agree that regional inversion has some advantages over a global inversion. But for regional inversions, accurate boundary conditions are required, and bias correction without proper bias characterization is also challenging (see Appendix A).

*(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.*

It has been changed to: ‘Several recent researches ...’

*(15) P1991 L6: Add “and the Scanning Imaging Absorption Spectrometer for Atmospheric CHartography (SCIAMACHY)”.*

It has been added.

*(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)*

This is a good point. A lot of development work has been completed on the retrievals since the publication of Chevallier et al., but we wanted to continue the scientific discussion that was motivated by this paper.

*(17) P1991 L9: What do you mean by “mis-fitting”?*

We have rewritten the sentence to avoid confusion.

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

We have added ‘for our global flux inversions ...’

*(19) P1992 L13: “spatial scales  $< O$ ” what do you mean?*

Which means at a spatial scale of several thousand kilometres. The O denotes the “order of magnitude” and is standard mathematical usage.

*(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.*

We have changed the sentence to: ‘many inversion systems are ...’. But, as discussed in Appendix A, developing a robust bias correction system is non-trivial, and required proper characterization of bias errors.

*(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*

We have changed the manuscript accordingly. For Europe, inclusion of TCCON sites reduced the uncertainty by about 15%.

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

We chose to include TCCON data because they improve the estimate of summertime peak uptake.

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

We want to define a reference system constrained by in situ data that was as accurate as we could make before comparing it against GOSAT data.

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

This is a good point, although smaller bias is expected for GGG2014. In the revision, we have taken into account these errors, by adding 0.5 ppm to TCCON observation errors (See Section 2).

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

Good suggestion, and ‘larger’ is added.

*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.*

The ‘aggregation errors’ is about the effects of the seasonable observation coverage. It is changed to: ‘...issues from the seasonal coverage of higher latitudes’

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

ETKF is the numerical algorithm to solve the optimal fluxes and the associated uncertainties. To avoid confusion, we replace it with EnKF.

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

We have revised the manuscript accordingly in Section 2 to provide detailed information about assumed temporal and spatial correlation of the a priori uncertainty.

*(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?*

We make it more clearly in the revision:

‘We also include monthly GOSAT  $X_{CO_2}$  regional biases over 11 TransCom land regions [Gurney et al., 2002] as parameters to be inferred together with surface fluxes from the joint assimilation of in-situ and satellite observations ...’

No correlation is assumed, because we don’t know.

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

Good suggestion. We add in the caption of Table 1:

‘Except INV\_ACOS\_INS\_DBL\_ERR and INV\_ACOS\_DBL\_ERR, the aggregated European annual uptake of the a priori fluxes is  $-0.1 \pm 0.52$  GtC/a.’

*(28) Bibliography: Please check all citations. As an example, Deng et al., 2013, is Printer-friendly Version*

We have updated citations.