Atmos. Chem. Phys. Discuss., 15, C691–C700, 2015
www.atmos-chem-phys-discuss.net/15/C691/2015/

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.

D. Baker

dfbaker66@gmail.com

Received and published: 12 March 2015

This manuscript examines the finding that annual CO_2 uptake across Europe is generally larger in inversions that assimilate column CO_2 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 X_{CO_2} 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 authors first compare a control inversion using *in situ* and TCCON data (INV_TCCON) to inversions using only GOSAT X_{CO_2} data (H-gain retrievals over land, only) from two different retrieval methods: ACOS v3.3 (INV_ACOS) and the University of Leicester v.4 (INV_UOL). Both GOSAT inversions give similar estimates of the annual net uptake for Europe in 2010 (-1.20 and -1.16 GtC a^{-1}), which is about double the uptake of what is obtained without using the GOSAT data (-0.56 GtC a^{-1}). Inter-

estingly, they find that most of the increase in European uptake occurs in the Feb-May timeframe, rather than during the height of the growing season, as in some other studies.

To evaluate whether the higher or lower European uptake values are more realistic, they compare CO_2 concentration fields from these runs to CONTRAIL takeoff/ landing data from two European airports, Amsterdam and Moskow. The difference is minimal between the curves using GOSAT data and those not — the difference between all of these and the actual CONTRAIL measurements is larger. Perhaps the INV_TCCON curve is closer to the CONTRAIL data overall, but it is not a clear difference. A hybrid forward run is then introduced that uses the fluxes from the ACOS GOSAT inversion (INV_ACOS) outside of Europe, and the fluxes from the reference case (INV_TCCON) inside Europe. When this is plotted next to the CONTRAIL data at the two airports, alongside the three inversion results, it lies above all of them (more positive). The intention of adding this case to the plot is not to show that this case would agree with the CONTRAIL data better (it is not clear that it does, and in any case the comparison is not really meaningful, since this is not one of the inversion cases examined here), but rather to make the point that there tend to be higher concentrations outside of Europe and lower ones inside for the ACOS GOSAT inversion (reflecting greater uptake over Europe balance by lower uptake around the same latitude band outside of Europe). 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.

The authors then perform about a dozen sensitivity experiments with their inversion

system that help to clarify why the greater uptake in Europe is occurring. Again, while these cannot say whether the inverse estimates with or without the GOSAT data are more realistic, they are quite helpful in understanding the mechanics of the inverse results. First, *a posteriori* fields from the reference run (INV_TCCON) are sampled at the GOSAT X_{CO_2} times/locations to give one the ability to replace the actual GOSAT measurements with ones that are consistent with the reference inversion: this gives the authors the ability to add/subtract the real GOSAT data without changing the results of the inversion by changing the coverage of the satellite data. They show that the TCCON-equivalent GOSAT samples give almost the same net flux result for Europe (-0.60 GtC a^{-1}; INV_ACOS_MOD_ALL) as obtained with the actual *in situ* and TCCON data (-0.56 GtC a^{-1}; INV_TCCON). Then they replace the TCCON-equivalent data with the actual GOSAT data within Europe (INV_ACOS_MOD_NOEU) and outside of Europe (INV_ACOS_MOD_ONLYEU) to show that the contribution of the GOSAT data to the increased uptake in Europe is about half due to GOSAT measurements over Europe and half due to those outside Europe. Also, they show that the increase in uptake in the Feb-May timeframe is almost entirely due to GOSAT measurements outside of Europe, rather than inside it. This is perhaps not surprising, since the coverage of GOSAT data over Europe during those months is not as great as during the middle of summer, but it does highlight the strong link between fluxes and measurements located far away from each other (in space and, potentially, in time) in global atmospheric 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?

Second, they add a +0.5 ppm bias to GOSAT measurements taken over Europe, both in the Feb-April and June-Aug timeframes. Such biases decrease the annual European uptake by about 0.1 and 0.15 GtC a^{-1}, respectively.

Third, they do inversions with both the GOSAT and *in situ*+TCCON data together, and in addition they solve for GOSAT X_{CO_2} biases for data inside of 12 land regions: the 10 Transcom land regions outside of Europe, plus the European Transcom region split into eastern and western parts. The annual mean European sink from these experiments is close to that given by the *in situ* + TCCON data reference inversion. 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^{-1} of the larger GOSAT uptake, according to the authors.

Fourth, sensitivity studies were done in which the *a priori* flux uncertainty was loosened by a factor of two: this was done both for the ACOS GOSAT-only inversion and the ACOS GOSAT + *in situ*/TCCON inversions. The greater weight given to the data resulted in a somewhat stronger European annual uptake in both cases.

Finally, sensitivity studies were run in which the *a posteriori* fluxes from the INV_ACOS and INV_UOL cases were used as the priors, and only GOSAT data inside of Europe were assimilated. To focus the impact of these measurements on Europe, the prior flux uncertainties for the 12 European flux regions were kept at the same values as used in the original GOSAT inversion cases, while the uncertainties at all regions outside of Europe were tightened to 1/3 their original values. The annual mean flux estimates for Europe that were obtained were similar to those from the INV_ACOS_MOD_NOEU and INV_UOL_MOD_NOEU cases, in which real GOSAT X_{CO_2} data inside Europe were inverted, with all the data outside Europe being set at that given by the reference case. The agreement between these two very different sensitivity study setups gives one confidence that the impact of the GOSAT data over Europe is being quantified properly.

The authors seem to have also done a couple of other inversions not listed in Table 1: they re-ran the INV_ACOS and INV_UOL GOSAT inversions, but first correcting the GOSAT X_{CO_2} values with the bias corrections estimated in the INV_ACOS_INS and INV_UOL_INS. At least I assume that they must have done these separate inversions, because I cannot come up with the 0.18 and 0.03 GtC a^{-1} corrections to the European annual flux mentioned on page 1998 and in the Conclusions using the results of any of the other sensitivity studies listed in Table 1. It would be good if the authors could give some more details about these inversions. 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?

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 ex-

planation: 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. 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^{-1}" — 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 X_{CO_2} 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_2 being transported into Europe, due to the assimilation of GOSAT X_{CO_2} data outside of Europe" and an "elevated CO_2 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_2 concentrations over each area? "Erroneous interpretation of X_{CO_2} 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 X_{CO_2} data are responsible for the increased uptake, and this has not been established.

In the third paragraph of the "Discussion and Conclusions", I agree with discussion of the estimated X_{CO_2} 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?

In the final paragraph, I agree with the authors that "This study highlights the adverse

effects of regional biases in current GOSAT X_{CO_2} 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 — the experiments they have done are valuable on their own merit and are worth publishing.

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.

Some more detailed comments follow:

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

p 1994, L 13: The global CO_2 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?)

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?

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

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.

p 1996 L 13-15: "...indicating an overestimate in the CO_2 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.

p 1996 L 24: replace "with a model" with "with those from a model"

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

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.

p 1997 L 24: "...to quantify systematic bias" — bias in what? Fluxes or measurements?

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_2 fields and X_{CO_2} data.

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.

p 1998 L 4-5: "To investigate the spatial pattern of the X_{CO_2} 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.

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.

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^{-1}": It is not clear where you got this 0.18 GtC a^{-1} 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)?

p 1999 L 4-5: "...is determined by a positive model bias of CO_2 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.

Interactive comment on Atmos. Chem. Phys. Discuss., 15, 1989, 2015.