

First of all, we thank Christian Frankenberg (in the following referred to as reviewer2) for his efforts in carefully reviewing our manuscript and his constructive comments.

Point-by-point answers to the comments of reviewer #2

1 General discussion

Reviewer 2: *The same holds for satellite retrievals, for which inferred posterior errors a) don't fully reflect observed errors and b) can be spatially correlated, which would also depends on the state of surface-atmosphere scattering. Neglecting these can be as counter-productive as stating that satellite data is too inaccurate for source/sink inversions.*

Authors: Please note that we do not neglect the raised points.

i) Validation studies using TCCON data showed that the inferred posterior errors of some of the used retrieval algorithms are too optimistic (e.g., Reuter et al., 2013). For this reason, the reported errors are scaled to match the validation results. The corresponding discussion can be found at P21841L9: “However, as some GOSAT data sets include unrealistically small errors, we scale them to match (on average) the single measurement precision determined from a validation exercise using the European TCCON sites shown in Fig. C1. We use the same validation set-up used by Reuter et al. (2013) and find the following scaling factors (single measurement precision from the validation / average reported error, both in ppm): BESD 2.25/2.39, ACOS 1.98/1.00, UoL-FP 2.50/1.06, RemoTeC 2.16/0.77, NIES 2.19/0.88.”

ii) As discussed at P21841L17, we assume spatially correlated errors for the SCIAMACHY data set: “... SCIAMACHY measurements can have direct neighbours thus error correlations become more likely (e.g., due to similar meteorological conditions). In order to make the error characteristics comparable with those of GOSAT measurements, we assume an error correlation length of 200 km (GOSAT's approximate average sampling distance in 2010) for measurements within one orbit. This introduces off-diagonal elements in S_e ...”. This means, only error correlations exceeding GOSAT's (approximate) sampling distance are ignored.

Reviewer 2: *...Simply taking the CarbonTracker uncertainties as uncorrelated errors and trusting their error-bars may be misleading.*

Authors: We consider this a misunderstanding because this is not our approach. i) We discuss that (unmodified) CarbonTracker errors are unrealistically large. P21840L17: “CarbonTracker uses a Kalman filter technique with a five-week assimilation window which results in monthly flux uncertainties considered unrealistically large. Therefore, we apply a scaling of 1/3 ...”. ii) We scale the CarbonTracker errors so that annual and seasonal uncertainties are similar to those reported in the literature. P21840L19: “... we apply a scaling of 1/3 so that the uncertainties of CarbonTracker's annual

averages become similar to uncertainties estimated by Basu et al. (2013) and Chevallier et al. (2014) inverting surface in situ measurements. The resulting monthly uncertainties (Fig. 1, bottom), with lowest values during the dormant season and largest values during the growing season, agree reasonably well with the inter-model spread of an ensemble of atmospheric CO₂ inversions (Peylin et al., 2013).” . iii) We assume month-to-month error correlations. P21840L25: “Potential seasonal biases are assumed to vary only slowly during the year and we assume an error correlation length l of three months between the bias elements of \mathbf{S}_a (the correlation between two months i and j is computed by $e^{-|i-j|/l}$). In order to better constrain the inversion, we add the same correlations to that part of \mathbf{S}_a corresponding to the fluxes.”

Reviewer 2: *I think the paper would raise less eye-brows if the focus would be on "growing season uptake" and not the annual sink, which is a mix of months constrained by satellite data plus CT filling in for the remaining seasons.*

Authors: The annual surface flux over Europe is dominated by the growing season. It is the nature of a joint or stepwise inversion that individual parts of the derived state are influenced to a greater or lesser extent by the different input data sets. This applies not only to our inversion study but (to some extent) to all satellite (NIR based) inversion studies investigating the European carbon sink. In the absence of inner-European soundings, global inversion models constrain European fluxes only by long range transport (to measurements outside Europe) and by the global carbon balance. This results in fluxes being more strongly influenced by simultaneously assimilated in situ measurements and/or the a priori during the dormant season.

We mention the fact that most information is obtained during the growing season within the abstract (P21831L22: “The highest gain in information is obtained during the growing season when satellite observation conditions are advantageous and a priori uncertainties are largest.”). The risk of underestimating respiration and/or decomposition during the dormant season is discussed at P21836L12: “The poor sampling during the dormant season does not allow for a larger error reduction and it cannot be excluded that CarbonTracker underestimates respiration and/or decomposition within this period, which would result in a weaker annual average sink. However, it should be noted that this is, in principle, accounted for by error propagation into the uncertainty of the annual averages assuming that the a priori fluxes in the dormant season are unbiased. Due to the lower activity of the biosphere during the dormant season, the a priori flux uncertainties in this season are smaller, which is consistent with results from an ensemble study of global inversion models showing the smallest inter-model spread in this season (Peylin et al., 2013).”.

The background model (CarbonTracker) provides a priori fluxes and corresponding concentrations. Therefore, changing the background model influences the results not only due to changed concentrations but also due to changed a priori fluxes. This means, our sensitivity study “MACC Background”

(Fig. 1, P21843L12) accounts also for the uncertainty of the a priori fluxes during the growing season (in addition to the assumed a priori uncertainty). Please note that nearly all results, figures, and performed sensitivity studies focus on annual averages so that a change in focus would result in a entirely different manuscript. Our approach is entirely consistent with the consensus that the growing season is the period of maximum carbon sink in Europe.

Reviewer 2: *The reason for less inter-model spread in the dormant season may also just be related to the fact that most models use similar simple parameterizations of ecosystem respiration, which is somewhat simpler than photosynthesis in the growing season.*

Authors: It is expected that a priori fluxes are better known in the dormant season and that the inter-model spread is correspondingly smaller: The net ecosystem production (NEP) equals the gross primary production (GPP) minus the total respiration (RES). Therefore, the uncertainty of NEP combines the uncertainties of GPP and RES. Photosynthesis (GPP) is reduced during the dormant season because of less available daylight. Lower temperatures reduce the metabolism rates and, therefore, RES during the dormant season. As a result, the absolute uncertainties of GPP and RES reduce (even though the relative uncertainties may remain large). As an example: in the absence of daylight photosynthesis stops and the uncertainty of GPP vanishes. We discuss this point in the manuscript at P21836L17: “Due to the lower activity of the biosphere during the dormant season, the a priori flux uncertainties in this season are smaller, which is consistent with results from an ensemble study of global inversion models showing the smallest inter-model spread in this season (Peylin et al., 2013).” This comment of reviewer 2, in principle, addresses all currently used inversion systems (see also the discussion of the last point).

Reviewer 2: *C1 and C2 (by the way, panel labels are missing)*

Authors: See bottom right.

Reviewer 2: *Looking at TCCON (C1) as well as Caribic (C2) mismatches, both the CT and the CT with BESD increment results indicate an underestimate of CO2 in the dormant season and an overestimate in the growing season, basically jumping from negative to positive deltas from March to April. This is already an indication that the dormant season has at least as many “problems” as the growing season and they point in the opposite direction. It seems not unlikely that the annual amplitude of NEE is underestimated, which is different than the annual integral of NEE, which can be small in magnitude and can be prone to many errors.*

Authors: We do not agree that Fig. C1-C3 shows indications for “problems” during the dormant season. From the discussion about the low error reduction during the dormant season and from Fig. 1, it is clear that flux increments in the dormant season are small and sometimes neglectable. This means that, according to Eq. C1, concentration increments can also only be very small so that optimised concentrations are similar to unmodified CarbonTracker

concentrations. As described at P21847L20 “except for a potential offset, the simulated concentrations shall ideally agree better with the measurements than the CarbonTracker concentrations”. For this reasons we apply an offset correction (by subtracting the mean difference) of all data shown in C1-C3 and state this explicitly in the figure captions: “A constant offset correction has been applied to the optimised and the CarbonTracker concentrations.” As a result, increases in the seasonal cycle amplitude are always visible in the dormant and the growing season even though significant concentration increments have only been applied in the growing season. In order to make this point clearer, we added to the captions of Fig. C1-C3 of the revised manuscript “by subtracting the mean difference”.

Reviewer 2: *I think the caveat that the derived annual sink is derived not only from satellite data but also from flux assumptions in the dormant season by CT should be mentioned in the abstract and ideally also in the title...*

Authors: We state within the abstract of the ACPD manuscript the following: “The highest gain in information is obtained during the growing season when satellite observation conditions are advantageous and a priori uncertainties are largest.” In order to make this point very clear, we replaced this for the revised version by: “The highest gain in information is obtained during the growing season when satellite observation conditions are advantageous, a priori uncertainties are largest, and the surface sink maximises; during the dormant season, the results are dominated by the a priori.”

Reviewer 2: *Pointing to caveats can also trigger future research, which this manuscript may instill ...*

Authors: We rephrased the last part of the conclusions which now reads: “New satellite missions with more measurements, higher spatial resolution, precision, and accuracy (e.g., OCO-2 or CarbonSat / CarbonSat Constellation, Crisp et al., 2004; Bovensmann et al., 2010; Buchwitz et al., 2013) have the potential to reduce the remaining uncertainties especially during the dormant season. They will enable flux estimations at high spatial resolution and contribute to improved process understanding on local, regional, and global scales.”

Reviewer 2: *... I think the various retrieval methods are indeed sufficiently different to de-couple their potential systematic biases. Biases in RemoteC and ACOS were found to not correlate with the same geophysical variables, for instance ...*

Authors: Thanks for sharing this information.

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