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Interactive Comment

Interactive comment on "Inverse modeling of CO_2 sources and sinks using satellite observations of CO_2 from TES and surface flask measurements" *by* R. Nassar et al.

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The manuscript of Nassar et al., "Inverse modelling of CO_2 sources and sinks using satellite observations of CO_2 from TES and surface flask measurements" covers a highly relevant topic, namely to use an established approach applied to new satellite data to obtain information on regional CO_2 surface fluxes. The manuscript is well written, important new aspects are covered and the topic is highly appropriate for ACP. I therefore recommend its publication after the major items discussed below have been considered by the authors.

We thank the referee for these positive comments.

I am not entirely convinced about the conclusions of the study that in fact new robust knowledge about regional CO_2 surface fluxes has been obtained from the TES retrievals as, for example, stated in the Abstract.

As with all inversion analyses, it is difficult to assess the benefits of the inversion because of issues with model and data biases, uneven observational coverage, etc... Nevertheless, we do demonstrate that TES data are providing useful additional constraints on the fluxes. Including TES data in the inversion improves the agreement with both the ship and aircraft data, and reduces the uncertainty on flux estimates in the tropics. We agree that it is not possible to draw firm conclusions about all regions from our results, but the South American tropical forest region, which is determined to be a slight sink (indistinguishable from neutral within the margin of error), gives a result very different from the strong source of our a priori, which was based on a different time period. This change from a strong source was consistent among all of our inversions for 2006 that use TES data (including earlier unpublished results) so we have greater confidence in the result for this region than some other regions. A more detailed qualitative analysis of factors contributing to this result is provided in our revised manuscript, and we no longer highlight the specific regional flux value in the abstract since the a posteriori uncertainty is such that the region could also be a weak sink.

There are indications that the TES retrievals suffer from biases. For example Figs. 6a and 6b show that the agreement of the model with the independent observations is significantly degraded if only TES is assimilated compared to the free running model and if only flasks are assimilated. The authors point out that the agreement is best if flasks and TES are both assimilated but as one can see from the scatter plots, the changes are very small so that it is hard to see a difference between the scatter plots where only the flasks are assimilated and the flasks and TES is assimilated (I agree that the metrics are better but only marginally; I would not over-interpret the small changes of the metrics). The changes are however large if only TES is assimilated. This indicates that the TES data have only a marginal influence on the assimilation

ACPD
11, C2908–C2914, 2011

Interactive Comment

which is dominated by the flasks.

We have attempted to correct biases in TES CO_2 data relative to CONTRAIL flask CO_2 (as described in the paper), which should reduce the biases, but this approach can not entirely eliminate them. We agree that the TES observations decrease the agreement with the ship-based surface flask data in Figure 6b, based on all metrics. As the referee notes, the metrics in Figure 6a, indicate that the TES CO_2 data improve agreement with the aircraft (CARIBIC) flask data, except for the variance (replaced by standard deviation in the revised manuscript). Although the improvements to R2 and F are rather modest, the improvement to the slope is large. We interpret these changes as an overall modest improvement with some associated noise coming from the observations. We also agree with the referee that the inversion is dominated by the flask data. As a result of the limited latitudinal coverage of the TES data, only weak constraints on the biospheric fluxes in the middle and high latitudes of the northern hemisphere result. The main point of our analysis is that TES data do provide additional (albeit modest) constraints on the flux estimates when they are ingested with the flask data – i.e. greater flux uncertainty reduction and better agreement with independent aircraft data.

This also indicates that the TES data and the flasks are not consistent.

We do not agree with the interpretation that the TES CO_2 and flask CO_2 data are not consistent. In Kulawik et al. (2010), validation with respect to flask observations was carried out and this consistency was demonstrated. Rather, we interpret the findings in the present work as highlighting the limitations of the model transport.

In addition, there is a large difference between the TES retrievals and the model as one can see from Fig. 2. Please comments on this. Can TES biases be excluded? This is critical as small differences (biases) will result in large flux changes. Please also show (add) more maps: at least the model with flasks assimilated (e.g., added to Fig. 2; see also following comment).

ACPD

11, C2908–C2914, 2011

In our original Figure 2, differences between TES and the model are typically on the order of a few ppm, either positive or negative. Models in general show less variability than either satellite or in situ aircraft observations in the mid-troposphere, so this is not surprising, and application of the TES averaging kernel and a priori further reduces this variability. Although remaining TES biases cannot be ruled out, detecting or quantifying them requires more extensive mid-tropospheric validation data, which are just not available for 2006. CARIBIC flask CO_2 data, which we have not used for validation would be one possible data set but this is instead retained as an independent data set for comparisons with the model a priori and a posteriori assimilated CO_2 distributions. Since the focus of this paper is not the flask inversion results, rather than show the flask a posteriori maps as suggested by the referee, we now expand Figure 2 to add maps showing 3-month averages (essentially seasonal) for TES and the model covering the entire year to give a more complete picture. The corresponding difference plots are also shown, but these are moved to Figure 4 where they can be compared with Jacobians to facilitate a qualitative understanding of the resulting inversion estimates for a key region (described later).

Concerning the regional results shown in, e.g., Fig. 3, it is not clear for me why the TES data suggest a sink for "S. American Tropical Forest". The a priori for this region is a strong source. Assimilating the flasks results in a weaker source. Adding TES turns this into a weak sink, which is highlighted in the abstract as one of the major findings of this study. Only TES retrievals over the ocean are used. According to the Jacobians shown in Fig. 4, "S. American Tropical Forest" CO_2 flux information is transported westward over the ocean where the TES observations are obtained. This indicates how TES obtains information for a land region although only ocean observations are made (used). Fig. 4 also indicates that this transport depends on the month and is larger in March compared to December (at least in 2006).

The referee may have misinterpreted Figure 4 which shows Jacobians for two different regions in two different months (South American Tropical Forests in March and African

ACPD
11, C2908–C2914, 2011

Tropical Forests in December); therefore it is not possible to determine from the figure in which month the transport is ‘larger’.

Nevertheless, the prevailing wind direction seems to be westward. Looking at Fig. 4, TES observes elevated CO_2 over the ocean west of "S. American Tropical Forest" (at least in May 2006 but also in Nov as one can see from the difference plots), whereas the free running model (using a priori fluxes corresponding to a strong source) does not show such a regional enhancement. Just from looking at Fig. 4, I would conclude that TES suggests that the "S. American Tropical Forest" region is a stronger source compared to the a priori fluxes used by the model. However, the inversion suggests the opposite. This may be due to the fact that the time period as selected for the various plots are different but this may also indicate a problem with the inversion. Please provide better evidence by showing (comparing) TES retrievals and model results (similar as done in Fig. 2 but for, e.g., annual and seasonal averages) that the TES retrievals in fact point to weaker "S. American Tropical Forest" fluxes (at least qualitatively - to do this quantitatively is the job of the inversion but I would like to see a more direct evidence of this major finding to ensure that the result in not an artifact of the mathematical machinery of the inversion).

The referee poses some valid questions here, for which our paper in the original form did not provide adequate information to answer. We now provide the Jacobians for the South American Tropical Forest region averaged in 3-month intervals so that they can be directly compared to the 3-month TES-model difference plots also now shown in Figure 4, replacing the pair of monthly difference plots that were previously shown in Figure 2. During the first 3-month period (JFM), the inversion is influenced by lower TES CO_2 directly off the west coast of South America (5°N-20°S) contributing to a much weaker Amazon source (or a sink). Based on these Jacobians, differences during the other periods (AMJ, JAS, OND) will have a much smaller influence on the annual results. To put this another way, since the Jacobian is most intense in JFM, this period should have the strongest influence on the annual flux for the South American trop-

ACPD
11, C2908–C2914, 2011

ical forests, and we note that during this period, latitude-dependent CONTRAIL bias corrections were not applied.

I am also concerned about the large source as suggested by the TES only inversion for the region "North American Boreal Forest" shown in Fig. 3c. There are not TES observations even close to this region. Despite this the response of the inversion is quite strong. Please clarify how this can happen and provide evidence that this is a result to compensate for regional TES biases or model transport errors.

The Jacobians for the North American Boreal Forest region indicate a zonal pattern of sensitivity with a fair amount of intensity between about 30-90°N, which decreases moving south, as demonstrated in the figure below for AMJ. Since TES CO_2 observations still have a reasonable number of degrees of freedom for signal between 30-40°N, this provides some sensitivity to the Boreal Forest CO_2 fluxes that is perhaps not expected. We acknowledge that errors in these midlatitude TES CO_2 observations or transport errors, will impact the Boreal Forest flux estimates.

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ACPD

11, C2908–C2914, 2011

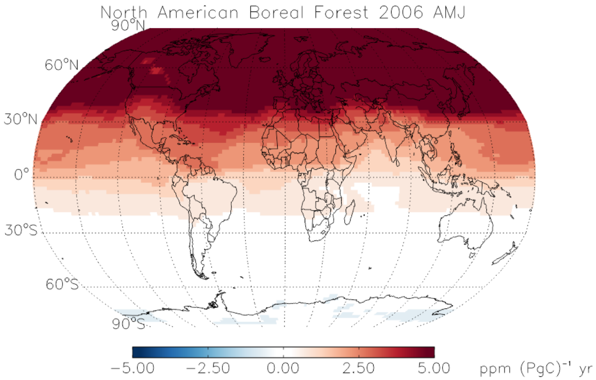

Fig. 1. April-May-June Jacobian for the North American boreal forests demonstrating some inversion sensitivity south of 40°N, the northernmost edge of the zone for which TES observations are includ

ACPD
11, C2908–C2914, 2011

Interactive Comment

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