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Atmospheric Chemistry and Physics Discussions

Interactive comment on "A biogenic CO_2 flux adjustment scheme for the mitigation of large-scale biases in global atmospheric CO_2 analyses and forecasts" *by* A. Agustí-Panareda et al.

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General comments

• *This paper presents an enhancement to the CO2 assimilation system used within the Copernicus tracer assimilation system at ECMWF. The enhancement is certainly useful and potentially quite important but it comes with its own problems. I believe these need to be discussed in the manuscript and addressed in how the new product is made available.*

We thank the reviewer for his insightful comments concerning the potential use of the CAMS CO_2 analysis product in flux inversion systems. The reply to each of the reviewer's points can be found below.

- *The enhancement addresses the problem of large-scale biases in the fluxes which underlie the prior concentrations used in the assimilation. These biases are a serious matter since they mean that the probability densities assumed in the assimilation system (centered on the true value) don't, in fact, hold. So this is a potentially valuable improvement.*

This is a very important part of the motivation of this work because the atmospheric CO_2 forecast provides the prior information to the CAMS atmospheric CO_2 data assimilation. As the reviewer points out, the data assimilation system is only designed to reduce the random error, not the bias. Therefore, it is very important to bias correct the prior atmospheric mixing ratios from the forecast before assimilating any CO_2 observations. We will include this point in the introduction of the revised manuscript to strengthen the motivation for BFAS.

- *The problem arises when we consider what the generated CO2 fields are used for. Although there is probably some benefit for improved retrievals of temperature and moisture by improving the CO2 field the overwhelming use for the assimilated CO2 products is in estimating surface fluxes. the statistical apparatus is identical to the assimilation of the CO2 fields and the same restrictions apply. Among them is a firm prohibition on reusing information and the requirement that observations and prior are independent. Both of these are potentially violated in any downstream use of the BFAS product. Let's deal with these two problems in turn.*

The reviewer has an important point in that users of the CAMS CO_2 analysis/forecast products need to know what is the input data going into the product and what is the final uncertainty of the product. This is the case whether the users are working on flux inversion systems, planning of field experiments or using the product as boundary conditions for regional models.

First of all, information on the uncertainty of the atmospheric CO_2 forecast with and without BFAS compared to the optimized flux experiments will be provided in terms of bias and root mean square error (RMSE) for different regions/seasons in the supplement of the revised manuscript using barplots as shown in Figures 1, 2, 3 and 4 in this reply.

Regarding the mixing of information in the analysis, this is currently not an issue for the CAMS CO_2 analysis system because the optimized fluxes used in BFAS are not based on satellite products; whereas the CAMS atmospheric CO_2 analysis is currently only assimilating satellite products. This will be clarified in the revised manuscript.

For the users, we envisage that the atmospheric CO_2 analysis/forecast will be used as boundary conditions for regional flux inversion systems. In this case the possible correlated errors between such an analysis and the measurements assimilated by the inversion within the regional domain will likely be marginal, given all the processing that is involved between the inversion to estimate the MACC optimized fluxes, BFAS and the IFS 4D-Var used by the CAMS atmospheric CO_2 analysis. The possibility to infer the surface fluxes directly from the IFS CO_2 analysis would mean that some information from the observations assimilated by the MACC flux inversion system would already be present in the CAMS CO_2 analysis via BFAS. Thus, we will detail the used observations in the revised manuscript.

• *I believe this paper is a potentially valuable contribution and look forward to the authors' revision. If the authors accept my first point about the mixing of data into their CO2 field then they also need to find a way of detailing which data was used to generate the flux fields that underlie BFAS.*

The flux fields underlying BFAS are primarily NEE modelled by the CTESSEL Carbon module in the IFS (Boussetta et al. 2013), which are then re-scaled using continental-scale climatological budgets from the MACC optimized fluxes of Chevallier et al. (2011, 2015). There is also some input from the EDGAR v4.2 anthropogenic emissions and the biomass burning emissions from GFAS (Kaiser et al. 2012). The information from these inventories is used to extract the NEE as a residual from the optimized fluxes.

The documentation of the different data streams going into BFAS and their access (via the Copernicus Data Catalogue and the EDGAR database) will be detailed in the supplement of the revised manuscript.

Specific comments

• *The assimilated CO2 field now includes information from a prior informed by a previous flux inversion. This inversion presumably used measurements from the in situ network, aircraft and/or TCCON. We can't tell which without a detailed examination of the papers that underlie that inversion. We need to know because, if we're going to use the BFAS product to drive a future inversion, we need to exclude those measurements. One might argue that the periods don't overlap but the evidence of the paper shows that the model-data mismatch is so strongly correlated from year to year (consistent seasonal errors in the pre-BFAS version) that this doesn't avoid the problem.*

In the revised manuscript we will mention that since the BFAS product contains information from the optimized fluxes, users should be aware that the optimized fluxes assimilated most available background air-sample monitoring sites (listed in the supplement of Chevallier et al. 2015, see http://www.atmos-chem-phys.net/15/11133/2015/acp-15-11133-2015-supplement.pdf.

Although we expect that observations ingested by the MACC inversion system of Chevallier et al (2011, 2015) will have an influence on the BFAS fluxes to some extent, we cannot quantify their degree of influence in this paper. We expect some information from the observations will be lost in the flux inversion process and specially in BFAS.

The processing in BFAS involves spatial/temporal smoothing of the optimized fluxes over land with a 10-year averaging to construct the climatology and then the inclusion of the model interannual variability. The influence from these surface observations will be further diminished after the assimilation of satellite products in the analysis. In order to ensure independence between the CO_2 analysis and the background-air observations ingested by the MACC inversion system, the atmospheric CO_2 analysis could be sampled at non-background-air locations characterized by a large influence from the satellite products.

• *The second problem, of the prior estimate for a flux inversion being partially reflected in the data we use is not new with BFAS. It exists in the original Copernicus products too. I'm unsure whether the mixing data and model information in the prior CO2 field makes this problem worse but it seems like it should.*

The BFAS processing should bring the mean error and large-scale spatial distribution of the CTESSEL NEE fluxes closer to the MACC optimized fluxes. This probably implies that the BFAS fluxes will not be completely independent from the prior in the MACC flux inversion system. Thus, if the same prior would be used again to infer fluxes from the atmospheric CO_2 analysis data, then it would be likely that BFAS would make the problem associated with their lack of independence worse.

• *Finally there is the question of the uncertainty of the BFAS CO2 field. There are two countervaling effects in play. First the bias correction of the prior has reduced residuals in the generated CO2 field so that uncertainties (which are the statistics of the difference between estimated and true values) seem to have reduced. On the other hand an extra process has been added to the assimilation with a new set of parameters to scale prior fluxes. These will have their own uncertainty and should (since the posterior CO2 field is sensitive to its prior) increase posterior uncertainty. Which of these wins out? I am always a little wary of criticizing a paper for things it did not do since no piece of research is complete. However it's an important general rule that products that are to* *be used as inputs to statistical procedures such as flux inversions need to specify their uncertainty as well as their mean.*

Plots showing characteristic biases and root mean square errors of the BFAS CO_2 field for different seasons/regions will be included in the supplement of manuscript (see Figures below). These plots use all the observations from the NOAA Obspack (2015) dataset (excluding only the observations from CONTRAIL and HIPPO flights).

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FULL FIGURE CAPTIONS

Figure 1: Mean error of atmospheric CO_2 dry molar mixing ratio [ppm] for different forecast experiments (see legend) with respect to insitu and flask observations for different seasons and regions (N20N: north of 20^oN; Trop: between 20^oS and 20^oN; S20S : south of 20^oS) with a separation between land and sea points denoted by a preceeding "L" and "S" in the region name respectively. The observations were extracted from the NOAA Obspack (2015) dataset in 2010. The number of observations used for the statistics are shown as grey bars in the panel below each plot.

Figure 2: Root mean square error of atmospheric CO_2 dry molar mixing ratio [ppm] for different experiments (see legend) with respect to insitu and flask observations for

different seasons and regions as described in Fig. 1. The observations were extracted from the NOAA Obspack (2015) dataset in 2010. The number of observations used for the statistics are shown as grey bars in the panel below each plot.

Figure 3: Mean error of atmospheric CO_2 dry molar mixing ratio [ppm] for different experiments (see legend) with respect to NOAA aircraft vertical profiles (Sweeney et al. 2015) in the free troposphere (1000 m above surface) for different seasons and regions as described in Fig. 1. The observations were extracted from the NOAA Obspack (2015) dataset in 2010. The number of observations used for the statistics are shown as grey bars in the panel below each plot.

Figure 4: Root mean square error of atmospheric CO_2 dry molar mixing ratio [ppm] for different experiments (see legend) with respect to NOAA aircraft vertical profiles (Sweeney et al. 2015) in the free troposphere (1000 m above surface) for different seasons and regions as described in Fig. 1. The observations were extracted from the NOAA Obspack (2015) dataset in 2010. The number of observations used for the statistics are shown as grey bars.

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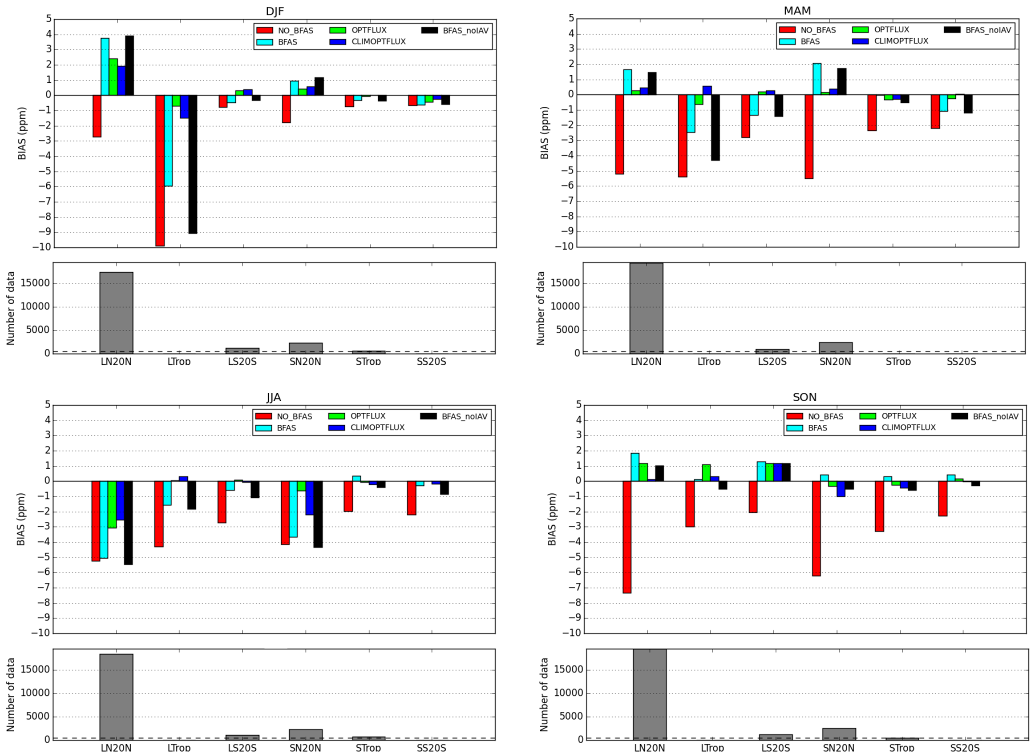

Fig. 1. See main text for full figure caption.

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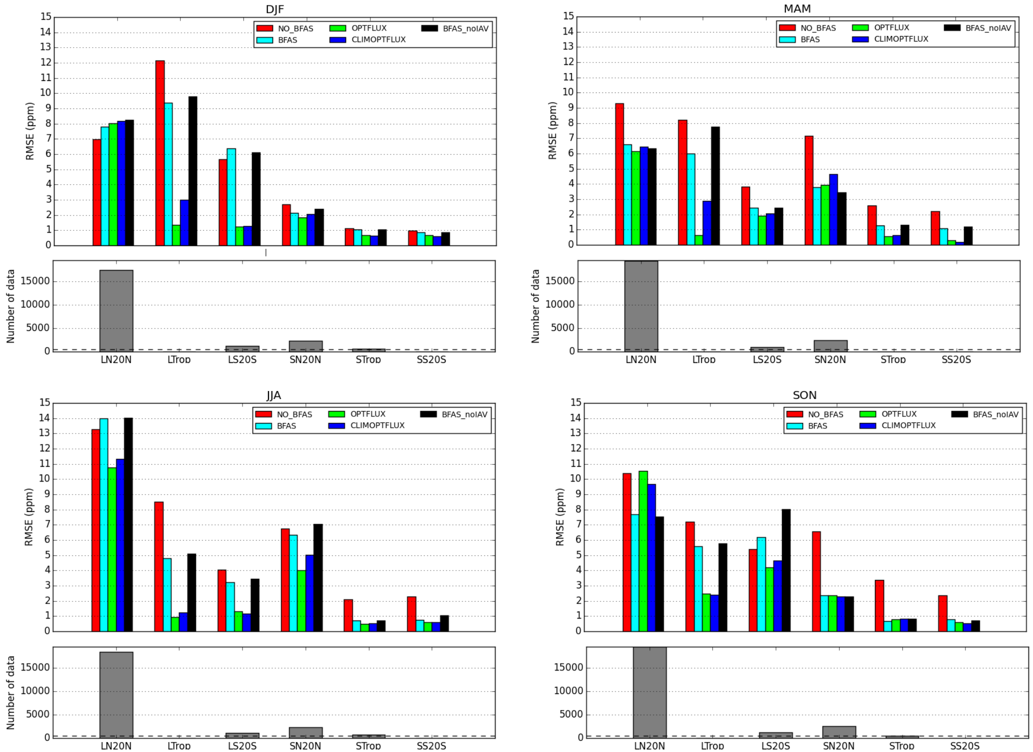

Fig. 2. See main text for full figure caption.

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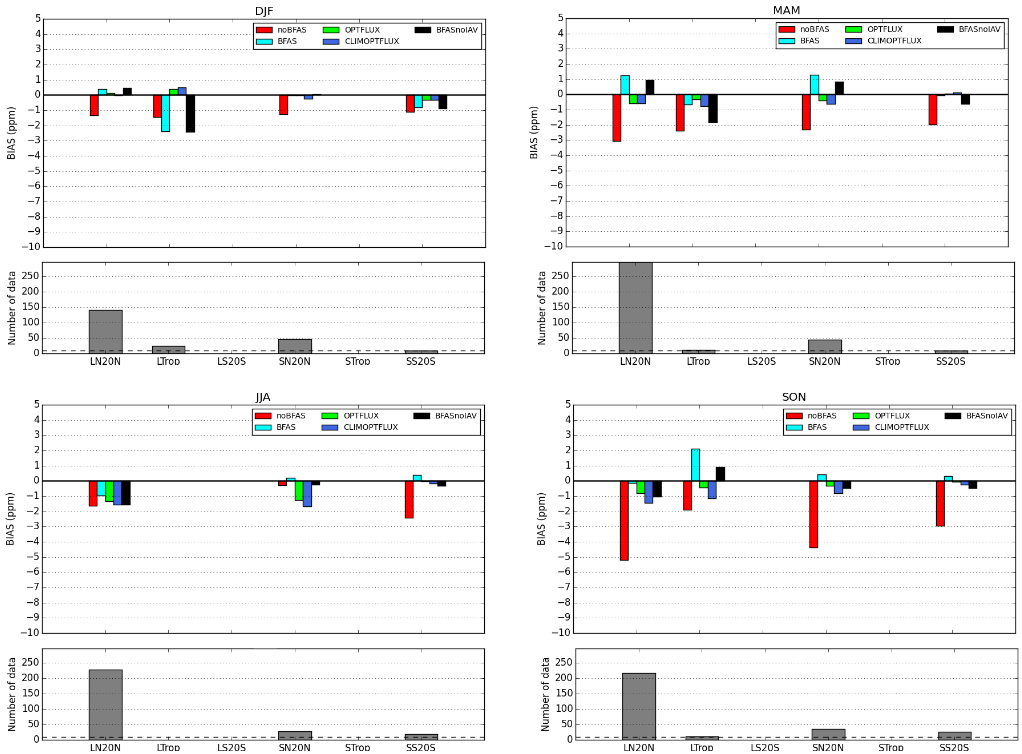

Fig. 3. See main text for full figure caption.

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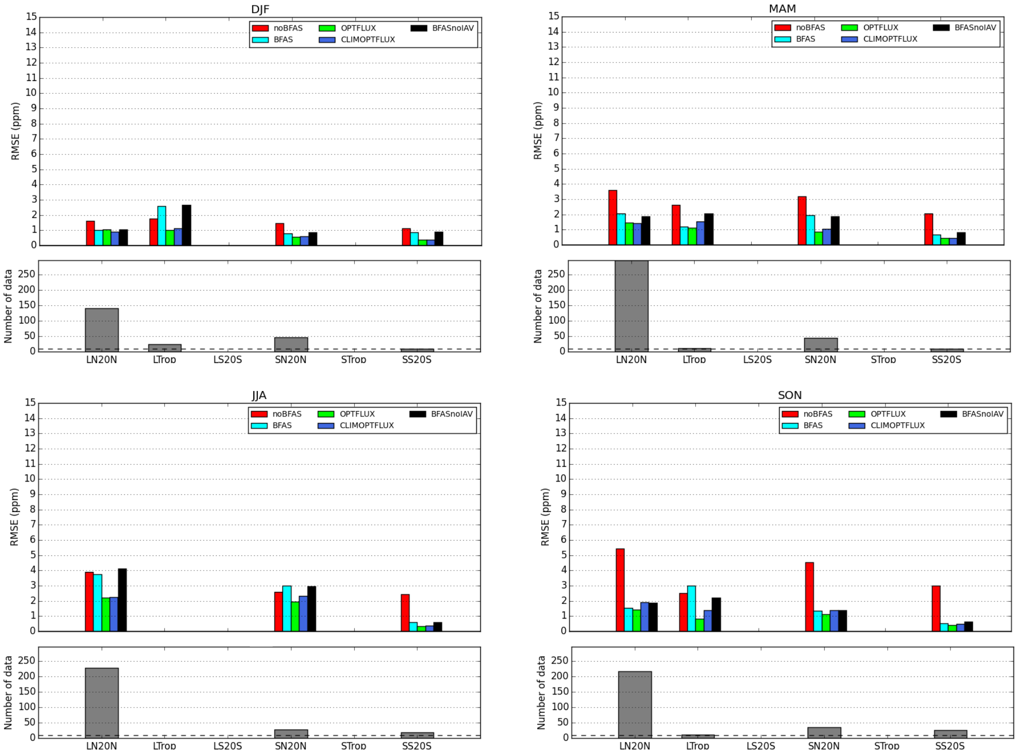

Fig. 4. See main text for full figure caption.

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