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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Importance of fossil fuel emission uncertainties over Europe for CO_2 modeling: model intercomparison" *by* P. Peylin et al.

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Please find below detailed responses to reviewer's comments. The long delay between this response and the initial comments is due to a change of laboratory, excess work load, and personal complications. Thank you for you patience and for considering these responses.

Philippe

General comments

This looks like a useful contribution to the literature but there are some issues I would like to be clarified/addressed. First, I agree with Gurney that some of these results are intuitive (in some circumstances similar results have been published elsewhere) and therefore require less text and figures. I have refrained from correcting grammar and spelling.

Response:

As detailed also for the first reviewer, we agree that part of the results on the forward model simulations could be condensed and summarized, Although not particularly new in its concept (the transport of several fossil fuel emission inventories), this forward modelling brings however new results in the sense that:

* It uses for the first time a relatively large ensemble of transport models including meso-scale models.

* The fossil fuel emissions inventories include a new highly resolved estimate (in space and time) for Europe.

* The resulting concentration fields are analysed simultaneously at all temporal scales (annual, seasonal, synoptic and diurnal).

* The concentration differences induced by varying “transport model” or “fossil fuel emissions” are compared and quantified in a rigorous way.

* 14C derived fossil fuel CO2 data are compared to the results of several transport models.

We thus have substantially shortened the forward modelling section:

* We decreased the number of figures in the main text: we removed figure 4b, while keeping fig4a and adding it to figure 3 as a third panel. We moved figures 6 and 8 to the supplementary material.

* We shortened the text (over 30 %) in order to keep only the main messages: this con-

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cern sections: 3.1 “FFCO2 Concentration time series” and 3.2 “Surface concentration fields”. (see text attached at the end of these responses)

As for the grammar and spelling we have checked more carefully the entire manuscript and hopefully have improved it substantially.

What I took away from this work is that forward and inverse model uncertainties from neglecting the sub-annual temporal variation of fossil fuel emissions are small compared to uncertainties due to model transport. (Only when monthly mean concentrations are considered is the spread of forward model concentrations due to assuming constant fossil fuel emission estimates comparable with the forward model spread due to transport uncertainty.) However, there remains an aspiration in the CO2 modeling community to move towards progressively finer temporal and spatial resolution inventories, which is clearly not justified if there is 1) no ground-truthing of the resulting CO2 fluxes/concentrations, and 2) no verifiable improvement in flux estimates (as suggested here for Europe). How well do hourly/daily fossil fuel emission inventories describe regional rush-hour traffic, country-specific vacation periods (particularly over Europe), anomalous hot/cold winters and summers, etc, etc? Incorrect specification of fine temporal and spatial emission distributions (and uncertainties) could potentially lead to incorrect flux estimates via inverse model calculations in just the same way that coarse resolution inventories can. This could easily be addressed via simulations. I think it would be useful for the paper to include some discussion about some of these issues.

Response :

We agree with the reviewer that moving towards progressively finer temporal and spatial resolution inventories is fully justified if there are ways to validate/evaluate independently the new estimates. Although we do not have currently such an approach (at the required spatial/temporal resolution), there is a large effort in the scientific community to develop new observing systems to verify declared anthropogenic emissions and

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emission reductions, either based on remote sensing CO2 measurements (GOSAT, OCO and other future missions) or on denser surface CO2 and 14C measurement networks. In the second part of his comment, the reviewer suggests that simulations could be used to assess the impact of incorrect specification of fine temporal and spatial emission distributions on the flux estimates via inverse model calculations. We agree with this suggestion but these simulations would require the use of transport model at higher spatial resolution than that of the models used in this study (see response to the general comment of reviewer 1). However, our current set of simulations provides already useful indications to discuss these issues. We thus have improved the discussion in the section 4 "impact on inversion of ecosystem fluxes" (see responses to reviewer 1 general comments) and conclusion sections to highlight the potential large effect of incorrect specification of finer temporal and spatial resolution inventories. The IER_hourly inventory provide an ideal case of detailed resolution over Germany (including rush-hour traffic, country-specific vacation periods, climate anomalies, for one particular year) and coarser resolution over other EU countries.

We added in section 2.1 at the end of the "Comparison of the different emissions inventories" the following sentence: "The large differences between the IER_hourly and the Edgar_hourly emission variations over Germany indicate the importance of using country specific information such as rush hour traffic, vacation periods, regional climate variations,....".

We also improved the conclusion adding in the second paragraph "...However these impacts and especially the impacts from incorrect specification of fine temporal and spatial emission distributions could potentially be much larger with meso-scale inversion systems." and in the following paragraph: "... For example, the IER emission inventory used in this study is much more precise for Germany than for other countries, which can lead to systematic FFCO2 concentration differences between stations and induce critical biases in the inversion results. We also anticipate that country specific information for rush hour traffic, vacation periods, or the type of consumed energy

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(fossil, renewable, nuclear) will directly impact the temporal emission distributions. The use of higher resolution transport model (such as REMO) will produce larger temporal and spatial concentration gradients (see section 3.2), which will in turn directly impact the retrieved biosphere fluxes."

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Specific details

Page 7471, line 1. I would not make the connection between a) the amplitude of model concentrations at HUN being half of what was observed at this site and b) day-to-day fossil fuel emissions are therefore essential to understand day-to-day variations of CO2 concentrations at HUN. Surely model transport alone could explain this model bias?

Response: We agree with the reviewer that our statement was too strong and that transport model biases could explain all differences with the observed concentration. We thus have suppressed this connection.

Page 7472, line 6. Please provide a reference for the boreal rectifier effect being more pronounced than elsewhere.

Response: The reference could be Denning et al. 1995: figure 1 of this paper shows the spatial distribution of the seasonal rectifier effect using one particular model. It clearly indicates the larger effect over boreal regions. However, given the reduction of the "forward modelling" section we have dropped the comparison to the biosphere rectifier effect.

Page 7473, line 10. Figure (5) (bottom)?

Response: The figure-reference was wrong. It has been corrected

Page 7474, line 28. Hot spots are less pronounced during summer due to enhanced vertical mixing during daytime. Is that a statement from work done in this study? Does this mean that resulting flux estimates are less sensitive to temporal and spatial reso-

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lution during summer?

Response:

Such statement comes mainly from the work done in this study but can not be considered as a new result as it is also illustrated in previous tracer transport studies. The impact of such statement on resulting flux estimates from atmospheric inversion is complex. On one hand, the smearing out of the hot spots fluxes in the concentration domain implies that the estimated fluxes will be less dependant on the spatial and temporal resolution of the fossil emissions. But on the other hand, the ability of the "atmospheric inversion" to accurately estimate at high spatial resolution the surface fluxes will decrease, i.e. the "spatial resolution power" of the inversion becomes smaller. Indeed the sensitivity of the atmospheric concentrations to regional surface fluxes becomes smaller. An in depth discussion of that particular point is beyond the scope of the paper but we now briefly mention the implication for the sensitivity of the flux estimates to details in the fossil fuel emission resolution. We added:" As a direct consequence, the estimated fluxes from atmospheric inversion will be less sensitive to the spatial resolution of the FFCO2 emissions in summer."

Discussion. Improving the representation of fossil fuel CO2 emissions is worthy goal iff they can be verified, but there is still nothing in the current observations that can be used to help attribute observed CO2 concentration variations on daily/weekly timescales. I think this should be stated explicitly.

Response:

We only partly agree with the reviewer: improving the representation of fossil fuel CO2 emissions is worthy goal even if the new emission estimates can not be yet verified. Refined spatial and temporal emission distributions will have a direct impact on atmospheric CO2 inversion. The only requirement is that new fossil fuel emission estimates should be more likely, in a probabilistic sense, than any previous estimates, even if they can not be yet verified by independent atmospheric measurements. There is currently

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a large effort in the scientific community to launch and design new space missions to verify anthropogenic CO2 emissions (OCO-2, CarbonSat, . . .) or to develop a network of 14C-CO2 atmospheric measurements to separate fossil fuel contribution from the biosphere contribution. However we agree with the reviewer that there is currently no existing observation system that can attributes accurately observed CO2 concentration variations on daily/weekly timescales. We have thus stated this point more clearly in the conclusion of the paper (last paragraph). We added: ". . ..However, current observation systems do not allow yet to accurately attribute observed CO2 concentration variations on daily/weekly timescales. Overall, improvements of the transport models are clearly needed before an independent verification of emission inventories through comparisons of simulated and observed fossil fuel CO2 might become feasible.".

Figures in general. Legend text could be larger.

Response: We have slightly increased the size of the text legend of the different figures.

Figure 2. Can the authors explain why there is so much variability in the German weekly fluxes during summer months?

Response:

The large weekly flux variations over Germany in the "IER" inventory come from the fact that the product is specific of one year (2000) and that it accounts for major sources of flux variations, including in particular: - Day to day climatic variations (mainly temperature) and their impact on the energy demand for residential heating. This is probably the main source of variation. - Socio-economic factors such as the "vacation-period" for the transport sector and for the industrial energy consumption, these factors changing from week to week. The resulting variations are indeed significant and larger for Germany than for other countries because the temporal and spatial resolution of the "IER" inventory rely on much more detailed and calibrated databases for Germany and that temperature dependencies (based on measured temperature) is only effective for Germany. We have slightly reinforced this point in the text at the end of the descrip-

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tion of IER product: "...Note that the IER product uses more detailed and calibrated databases for Germany than for the rest of Europe and accounts for temperature dependencies in Germany only (based on measured temperatures), which leads to large weekly flux variations (see figure 2)".

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REVISED VERSION OF SECTION 3.1 and 3.2 (in latex)

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\subsection{FFCO$_2$ Concentration time series}\label{sect:resfor:timeseries}

CO$_2$ concentration time series were simulated for all European measurements sites (see site location at http://www.carboeurope.org/). For the sake of brevity, the discussion is illustrated with the results for one station, the Hegyhatsal tall tower (115m) in Hungary (referred to as "HUN"). Additional figures for HUN and for a second site Schauinsland (SCH, a mountain station in Germany that is usually incorporated in inversions) can be found in the supplementary material. We restricted ourself to these two sites as they can be considered representative of several European stations. To deal with the large number of factorial simulations, 7 transport models x 4 FFCO$_2$ emission inventories, we reduce the number of time series by displaying means across models and means across emissions, in order to compare the effect of emission pattern differences versus transport model differences on the simulated concentrations.

\vspace{0.3cm} {\it Seasonal cycle}

Figure~\ref{fig:conc_mean} (top) displays the daily mean FFCO$_2$ concentrations averaged across all models for each emission inventory at HUN. Like in most inversion set-ups, we selected daytime values (average over 10h to 17h LT), because existing transport models are known to have difficulties in simulating the stability of the nocturnal planetary boundary layer (PBL) \citep{geels:07}. The simulated time series show large synoptic variations, up to 5 ppm, superimposed on a seasonal cycle of

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roughly the same size and a trend of few ppm/yr due to the accumulation of emitted FFCO$_2$. These features are common to all stations (fig.~\figsupConcMean, supplementary material), but the amplitude of the synoptic events and the seasonal cycle varies depending on the location of the site to major industrialized regions. All tracers show a seasonal cycle, which in the case of constant emissions reflects seasonal changes in the atmospheric transport, especially stronger mixing during summer than during winter over Europe. At HUN, the phase and amplitude of the synoptic events are rather similar for all tracers, which indicates that the variation of atmospheric transport is the dominant factor causing day to day variations of FFCO$_2$ at this site. Note that the observed amplitude of the synoptic CO$_2$ variations at HUN is roughly two times larger than the one obtained using FFCO$_2$ only.

Time series for the average across all emission inventories for each transport model (Figure~\ref{fig:conc_mean}, middle), show similar seasonal and synoptic patterns but with much less agreement for the amplitude and the timing of the synoptic events. On average the amplitude of the synoptic events is larger for the mesoscale models (REMO, DEHM, CHIMERE and COMET) and TM5 (zoomed model) than for the coarse global models (TM3 and LMDZ) and the differences between models are largest in winter. Overall, the transport model spread dominates over the spread induced by the four different fossil fuel emissions. Similar results are found at all European stations, (supplementary material).

The effect of neglecting temporal variations in fossil fuel emission, is illustrated with the differences in simulated concentration between \edgh\ and \edga\ emissions at HUN (figure~\ref{fig:conc_mean} bottom). We observe a marked seasonality for all transport models with positive values in winter (up to 3 ppm) and slightly negative values in summer (up to -1 ppm). This difference combines (i) the seasonality of the \edgh\ source with (larger emissions in winter due to larger heating sources ($\sim$50\%) compared to the constant \edga\ source; section \ref{sect:method:emis}), and (ii) the seasonality of the atmospheric vertical mixing with the strongest mixing during sum-

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mer time. Both effects act in the same direction and the amplitude of the resulting seasonal variation ranges from $\pm$0.5 ppm at remote stations like Pallas in Finland up to $\pm$5 ppm at stations close to industrial areas (i.e., the Cabauw tower in the Netherlands). Note that the covariance between seasonal variations in emissions and transport contributes about 1 ppm to the “seasonal rectifier effect” described for CO$_2$ by \cite{kee-89a}. The concentration differences between \ierh\ and \edga\ emissions (not shown) show more complicated temporal patterns, indicating that spatial differences are as important as the effect of neglecting the temporal variations in the emissions.

\vspace{0.3cm} {\it Diurnal cycle}

Figure~\ref{fig:conc_jul} (top) displays the hourly concentrations averaged across all transport models for each tracer at HUN for one week in July. A large diurnal cycle of up to 2 ppm is observed, with larger concentrations during nighttime than during daytime. For the constant emission fields (\trc\ and \edga), the simulated diurnal variations are fully explained by diurnal variations in the PBL height. For the time varying fluxes, increased fossil emissions during daytime oppose this effect and reduce the diurnal cycle in the simulated summer concentrations by up to 1-2 ppm depending on the station. Similar results are ssupleen at all stations close to source regions. At remote stations or mountain stations (SCH, figure~\figsupConcJul, supplementary material) the time series display almost no diurnal cycle in summer. In winter, no clear diurnal cycle is observed at HUN and SCH (see supplementary material): synoptic events appear to be the dominant source of FFCO$_2$ short term variability, and both spatial and temporal differences between the emission inventories cause significant concentration differences (up to 4 ppm at HUN).

Figure~\ref{fig:conc_jul} (bottom) shows similar time series but now for the average across all tracers for each transport model. The scatter between the different transport models is much larger at all stations, with model to model differences up to 6 ppm, and complicated temporal patterns. For example, TM5 and partly COMET have a large

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diurnal cycle in summer with elevated FFCO$_2$ concentrations at night compared to daytime (amplitude of nearly 5 ppm), unlike TM3 and LMDZ. In winter (see figures in supplementary material), no clear coherent variations can be discerned between the models at the daily time scale: synoptic events are clearly visible but their amplitudes strongly differ between models (from 2 ppm in TM3/LMDZ to 10 ppm in the other models).

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 7457, 2009.

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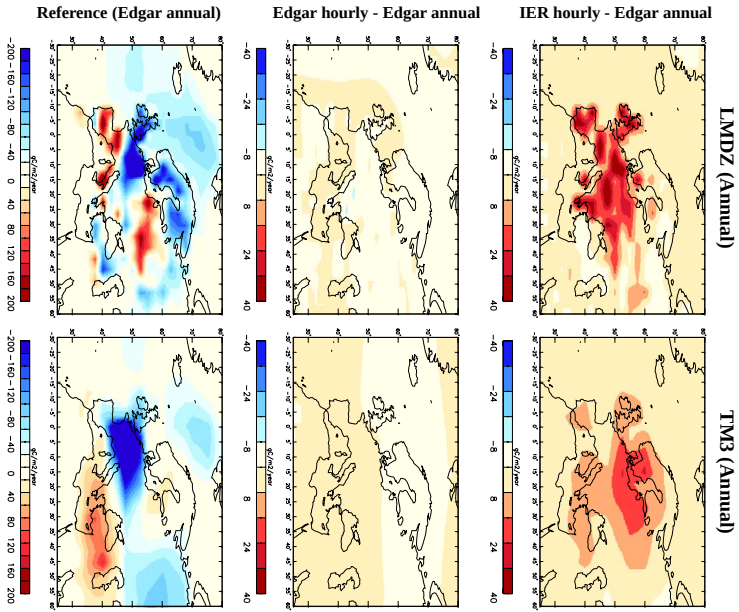

Fig. 1. ADDED FIGURE (short caption): Annual Fbio fluxes estimated with the 2 inversions with Edgar_annual FFCO2 emissions (lower panel) and the differences between IER_hourly or Edgar_hourly and Edgar_annual

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