

***Interactive comment on* “Probabilistic estimation of future emissions of isoprene and surface oxidant chemistry associated with land use change in response to growing food needs” by C. J. Hardacre et al.**

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Responses to “Probabilistic estimation of future emissions of isoprene and surface oxidant chemistry associated with land use change in response to growing food needs” by Hardacre et al.

We thank the anonymous reviewer and Laurens Ganzeveld for providing useful feedback on the submitted manuscript. Below we respond to individual reviewer comments (*italicized*).

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Response to comments from anonymous reviewer 1:

1) *There are 500 realizations for each future land use change scenario (A1 or B1), but it's not clear how the 500 realizations are obtained - is that done by randomly combining the different variables controlling/affecting the future land use? Are the changes of all these variables consistent with the corresponding scenario?*

The subset of $n=500$ land use change (LUC) realizations is selected from the full ensemble of $n=1000$ LUC realizations that was generated for each IPCC AR4/SRES scenario (A1, B1). The subset of 500 realizations comprises realizations for which the change in total global cropland is within the interquartile range (across the $n=1000$ ensemble), which is described in Section 2.

The $n=1000$ ensemble was generated by uniformly perturbing all the PLUM input variables, which describe rates of change in e.g. cereal consumption and cereal production within a country, within a fixed range around an initial starting point. The extent to which the PLUM parameters were varied was consistent with the IPCC-SRES AR4 scenario, and reported in Section 2.1, paragraph 5-6. For example, greater rates of increase in cereal consumption were explored for the A1 scenario (a high emission scenario) compared to the B1 scenario (a low emission scenario), where the range of rates of cereal consumption included negative rates, i.e. decreasing consumption.

We clarify these points in the paper, Section 2.1, paragraph 5-6.

2) *P33369 L24-27 - "increased cropland area isoprene emission factors assigned to a particular grid cell would not change" – why does the isoprene emission factor remain constant for the grid cell with the changes in vegetation composition?*

In the MEGAN model, which is incorporated in the GEOS-Chem model to calculate BVOC emissions, emission factor data sets and plant functional type (PFT) coverage data sets are provided for each PFT. These data sets describe the emission factor (in

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mg m⁻² h⁻¹) and proportional coverage (in m² m⁻²) for each PFT in each grid cell. The actual BVOC emission (in mg m⁻² h⁻¹) is calculated by multiplying the emission factor by the proportional coverage. The emissions from each PFT are summed across each grid cell. In our study we have assumed that the emission factors associated with the PFT in each grid cell do not change. However, the proportional coverage of the plant functional types will likely change and therefore result in changes to the actual BVOC emissions from a grid cell. For example, if a grid cell initially comprising 25

We think that it is reasonable to assume that where the coverage of a particular PFT expands within a grid cell, existing species will be planted as these will be optimal for the local conditions and/or culture. However, if some of the increase in cropland is for biofuel, we do change the emission factor as a limited number of biofuel feed stock species were used in this study. Using the above example; if 5

We clarify these points in the paper, Section 2.4, paragraph 2.

3) I would suggest the authors to compare their calculated land use change (in particular the changes in cropland) by 2030 to existing literature and comment on the possible consistence or discrepancies in the projections.

This is a good suggestion. Estimates of future global cropland area are highly variable depending on the scenario around which future assumptions are made and the nature of the cropland, whether for food, grazing or biofuel cultivation. We have included estimates of future cropland in Section 1 and where possible we have compared our estimates of changes in cropland area with relevant literature values e.g. Ganzeveld et al. (2010), Section 4. However, following the reviewer's suggestion we have also included more direct comparisons of future cropland area for the A1 and B1 scenario obtained from Nakicenovic et al. (2000) with our estimates in Section 3.1.

4) Fig.3 - the unit of km² is really confusing - is it actually km²/grid?

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The reviewer is correct. The change in land cover is plotted as the change in area (km² per grid cell). We have changed the plot accordingly.

Responses to comments from L. Ganzeveld:

a) General comments

1) *Suitability of ACP for presenting this study?*

The interdisciplinary nature of this study means that it does not fit naturally within the scope of any particular Copernicus journal, but we felt that the emphasis of the material (impact of LUC on tropospheric chemistry) presented fell within the scope of ACP.

We use a novel probabilistic method to assess the effects of LUC on atmospheric composition which we believe fills a gap in this field of research and complements other such studies such as that by Ashworth et al. (2012). Consequently, it is important that this study is presented in a high impact journal such as ACP.

We acknowledge that the description of the PLUM model and LUC scenarios is fairly detailed. However, as we are awaiting publication of the study by Baumanns et al. (2012) which describes and evaluates the PLUM model as well as considering a scenario study, it has been necessary to also include a reasonably detailed description of the PLUM model here.

2) *Comparison of changes in AC/exchange with anthropogenic emissions*

Changes in anthropogenic emissions are an important consideration for future atmospheric composition. We have purposely focussed on isolating changes in atmospheric composition that result from changes in BVOCs due to LUC, which Lathiere et al. (2010) suggested was, in fact, the major driver of changes in BVOC emissions. We acknowledge that the inclusion of changes in anthropogenic emissions

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will have further effects/feedbacks on climate, the earth system and importantly for this type of study, vegetation cover, which are briefly discussed in Section 4, paragraph 7, of the paper.

3) *Streamlining results*

We have combined the results section for southern Africa, Brazil and Tropical South America where similar patterns in cropland expansion/deforestation resulted in similar patterns in the changes to surface oxidant chemistry in those regions. In addition, local scale results are no longer discussed by region. We have also included an extra section, which focuses on the large changes at the local scale and suggests where further research should be done at the local/regional scale.

(b) Replies to specific comments

1) *Line 179: Explanation of 1st and 2nd generation biofuels*

We have included a brief definition of first and second generation biofuels in Section 2.2, paragraph 1.

2) *Comments related to Section 2.2*

In the current version of PLUM, LUC due to biofuel cultivation is not described (but planned for a later version of the model) so LUC in the n=1000 ensemble is only due to changes in food production. However, it is important that some estimate of LUC due to biofuel cultivation is included in this type of study and in order to keep the number of scenarios within reason we only investigated two simple future biofuel scenarios. In the initial investigation of LUC on BVOC emissions we did not know how the LUC realisations would affect BVOC emissions so we investigated all realisations (n=500) within the interquartile range of the n=1000 ensemble. We found that there was little divergence in BVOC emissions across the interquartile range (n=500) and that there

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were comparatively large differences between the two biofuel scenarios. For the more detailed investigation of the effects of LUC on atmospheric composition we did only use realizations representing the median and the extremes of the IQR. This is clarified in Section 2, paragraph 1 of the paper.

3) *Section 2.3: Effect of different maps of distribution of global cropland*

Although the country based LUC data from PLUM is originally downscaled to a 0.5o x 0.5o grid, this information is regridded to 4o latitude x 5o longitude during the model run. At this resolution small-scale differences in global cropland distribution will not be resolved. In addition, the plant functional types (PFTs) defined in this study, both in PLUM and MEGAN/GEOS-Chem) are quite broad, limiting the resolution of cropland location. We acknowledge that using a higher resolution model run, which was too computationally expensive for our ensemble-based study, would allow for uncertainty in land cover distribution to be explored. We have added a sentence to that effect in Section 2.3 of the paper.

4) *Line 235: Isoprene emission factors*

Please see the reply to Reviewer 1.

5) *Line 243: Soil NO_x emission factors*

The GEOS-Chem model calculates soil NO_x emission fluxes as a function of vegetation type, temperature, precipitation history, fertilizer application (if any) and a canopy reduction factor (Wang et al., 1998; Yienger and Levy 1995). In this study the vegetation land cover map was altered for each LUC realisation so that changes in NO_x emissions from fertilizer application were accounted for as cropland area distribution changed. We only altered the NO_x emission factors and only for certain crop types. This is clarified in Section 2.4 of the paper.

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6) *Line 269*

We thank the reviewer for this clarification. We have inserted a comma so that the sentence now reads: “For example if the rate of increase in crop yield was lower, the increase in global cropland area and corresponding decrease in forest and grass land area was greater, i.e. more cropland was required for food production when crop yields were lower (and vice versa).”

7) *Line 275* The reviewer is correct, global cropland area is changing relative to the baseline year, 1990. We have added text in Section 3.1.

8) *Line 300-305*

i) We have modified the text on lines 290–295 to read: “Figure 3 shows the simulated net changes in cropland area per country for the median realizations of the A1 and B1 scenarios in 2030, downscaled to a 0.5o x 0.5o (Section 2.3). Cropland expansion estimated for the 450 and Reference biofuel scenarios is included.”

For particular geo-politically unstable countries initial input data from FAOSTAT was unavailable. We have modified the text in Section 2.1 to read: “Countries for which FAOSTAT and CIESIN data were not available, including Democratic Republic of the Congo, Iraq, Afghanistan, Somalia, Oman and small island/city states are not included in PLUM.”

ii) In Section 4 we do state that the changes we see at the global scale are small (in line with previous studies), but that changes at the regional and particularly the local scales are important. We now include text in Section 3.2 to reiterate that the changes are small compared with uncertainty in estimates of the global isoprene burden: “However, the changes of $\pm 6\text{-}8$ Tg/yr reported here are very small compared to uncertainty in the global isoprene budget which is estimated between 402-660 Tg/yr (Lathiere et al., 2010)”

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iii) Please see our general response to this reviewer comment.

9) *Line 434*

Although the reviewer made a good suggestion, in editing the text in Section 3.3 we have removed this sentence.

10) *Line 441*

We have added the following text in Section 3.3.4 (local changes in surface oxidant chemistry) to highlight the over-estimation of isoprene mixing ratios in tropical areas: “Isoprene mixing ratios over tropical, low NO_x areas are overestimated in global models as a result of incomplete understanding and/or simplification of the complicated chemical and phenological processes (Ashworth et al., 2012). Studies by Archibald et al. (2010) and Hewitt et al. (2011) have respectively indicated that modifying the isoprene chemistry to simulate more realistic OH concentrations and including circadian cycles in isoprene emissions improve the agreement between observations and model simulations. However, in this study isoprene mixing ratios, and possibly the differences in mixing ratios between ZLUC and LUC scenarios, are likely over estimated in tropical regions.”

11) *Line 444*

In editing the results section we have removed this sentence.

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