Response to Referee #2

We are grateful to the reviewer for their time and energy in providing helpful comments and guidance that have improved the manuscript. In this document, we describe how we have addressed the reviewer's comments (italicized below). Page numbers refer to Discussion paper (*Atmos. Chem. Phys. Discuss.*, 13, 17717–17791, 2013).

The authors present the implementation of a photosynthesis-based isoprene emission simulation into a chemistry climate model. This effort represents an important step in the right direction in terms of the state of science for simulating isoprene emissions, and towards a more process-based approach for examining chemistry-climate couplings. The manuscript is well-written and thoughtfully motivated. While a paper focusing solely on model development and evaluation, such as this, would normally be better suited for GMD, this work should find sufficiently broad interest in the community for it to fit also in ACP. I recommend publication. Below are some comments and questions for the authors to consider.

1. How large are the implications of this model decoupling between LAI and GPP/isoprene emissions? i.e., GPP and isoprene emission are allowed to vary interannually according to environmental drivers, but the LAI is not. To what degree would this dampen the simulated interannual variability of isoprene emission?

The reviewer raises an excellent question. In this work, our goal was to describe and evaluate the free-running chemistry-climate model version using the simple (uncoupled) LAI algorithm because this version will be used in on-going and planned paleo studies of atmospheric chemistry in past hot and cold worlds. The reviewer is likely well aware of the pitfalls and problems associated with coupled prognostic LAI modeling. LAI response to climate change is highly uncertain and not robust across models (Migliavacca et al., 2012;Richardson et al., 2013). A complete mechanistic understanding of the processes that control the development and senescence of foliage is not yet available such that the current state of phenology modeling may even be considered qualitative at best. The simple LAI scheme used in this study does yield a realistic GPP seasonality (Figures 4, 5a). The GPP-LAI relationship must be nonlinear (sub-linear) because plants may allocate the additional assimilated carbon to any of several biomass storage sites (roots, stems, and trunks, leaves). At the same time, at four North American FLUXNET sites, variation in LAI was found to have the dominant control on GPP over meteorology (Puma, 2013). We have a working version of the model that reads in off-line annually varying MODIS LAI and find that interannual variability in isoprene emission is of similar magnitude to the version used in this study (1-3%). We also have a climate-sensitive phenology model version under active development and will apply this version in future work to examine quantitatively the impact of coupled LAI on the isoprene emission variability.

We have added in Section 2.1.1 (page 17725): "A complete mechanistic understanding of the processes that control the development and senescence of foliage is not yet available such that the current state of phenology modeling may even be considered qualitative (Migliavacca et al., 2012;Richardson et al., 2013)."

And in Section 2.1.1 (page 17726): "Application of LAI that is insensitive to climate may dampen the simulated interannual variability of isoprene emission in this model version."

And in Section 5 (page: 17744): "improvements in simulating isoprene variability may be achieved by including climate-sensitive phenology, variable atmospheric surface CO_2 concentrations and the effects of ozone on plant physiology…"

2. "Equation (5) does not simulate a temperature optimum after which isoprene emission rate decreases with further increases in temperature. Such high temperature conditions in isoprene emitting biomes rarely occur in nature at large ecosystem scales. Canopy-scale temperatures of this magnitude may occur under severe drought stress conditions when transpiration is significantly reduced. (. . .) Yale-E2 intrinsically captures the effects of changing stomatal conductance on canopy energy balance, which affects the canopy temperature, and thus the isoprene emission rate." But the corresponding effect on isoprene emission would be offset in the model by the accompanying increase in kappa, wouldn't it? Anyway, this model is developed (at least partly) for application in future climate simulations when such high temperature events will probably become more commonplace. So, how big an effect will omitting the isoprene temperature-turnover have then? Is it likely to introduce a significant bias for future (warmer-world) simulations?

Please see response to Referee #1, comment (10).

According to the photosynthesis/stomatal conductance model, the canopy temperature will tend to increase under severe drought (less evapotranspiration), which will act to amplify (not offset) the effects of the increase in kappa (decrease in C_i) on isoprene emission i.e. there is a 'double whammy'. We see this effect in the dry season Manaus dataset. The elevated canopy temperatures under the dry conditions are acting to increase isoprene emission (Section 4.2.5) even though GPP is suppressed due to lack of water availability for those conditions.

3. "In the current model, e does not vary with time of day or season". Since in reality base emission rates are higher for mature leaves, this will lead to something of an overestimate early in the growing season, correct? (note: yes, as shown later in the paper). This will have implications in terms of the timing of the seasonal transition from VOC to NOx-limited ozone chemistry in many parts of the world, which would matter if one were to look at interactions between ozone, plant physiology, and isoprene emission.

The seasonal transition from VOC to NO_x-limited ozone chemistry at mid-latitudes does not likely have a significant impact on ozone radiative forcing that is the primary goal of our global model framework. Ozone radiative forcing is most sensitive to precursor emissions in low latitude and high latitude regions, i.e. uplifted tropical biomass burning emissions that happen to be the dominant BVOC source region too. Whether global chemistry-climate models (~100-200 km horizontal resolution) are able to capture correctly the chemical dynamics of this transition would be the subject of another interesting manuscript.

We have added to Section 5 (page 17745): "….that will allow us to account for the effects of leaf age on the isoprene emission, which has implications for atmospheric chemistry, for instance, timing of the seasonal transition from VOC to NO_x-limited ozone production."

4. "In contrast, the CCM community often assumes significantly lower isoprene emissions in preindustrial versus present day conditions in estimates of anthropogenic ozone radiative forcing". Say why this would be? Due to temperature changes? In any case, this point is not readily apparent from the references cited. E.g., Fig 1 (panel f) of the Young et al. paper shows quite consistent isoprene emissions from pre-industrial to present-day.

In the early days of coupled global chemistry-climate modeling (i.e. the IPCC TAR), isoprene emissions were often reduced by 50% to simulate preindustrial conditions. No rationale was given, although I suspect, as the reviewer suggests, it was an attempt to mimic effects of the slightly colder climate conditions.

We have removed (page 17732): "In contrast, the CCM community often assumes significantly lower isoprene emissions in preindustrial versus present day conditions in estimates of anthropogenic ozone radiative forcing e.g. (Mickley et al., 1999;Young et al., 2013)."

And replaced with (page 17732): "In the most recent community assessment of anthropogenic ozone radiative forcing led by the Atmospheric Chemistry and Climate Model Intercomparison Project, only 4 of 15 participating state-of-the-science global chemistry-climate models included climate-sensitive isoprene emission (Young et al., 2013). Those 4 models all projected a small increase in isoprene emission from preindustrial to present day in response to temperature change. 9 out of 15 models prescribed isoprene emission and used the same off-line input data for preindustrial and present day."

5. Section 4.1.1, dependence on GPP versus temperature. But GPP also varies with temperature (Beer et al., 2010), right? Do you have any issues with multicollinearity in this analysis?

It is true that GPP depends on temperature but is not a linear function of temperature in the model. In the climate model for a specific season, GPP variability will be more related to precipitation/soil moisture variability. The relationships may already be fully apparent to the more mathematically inclined reader directly from equation (1). The MLR analysis emphasizes the high temperature-drought -> low GPP/isoprene conditions that will not exist in models that do not incorporate the effects of soil moisture availability.

6. It's difficult to assess the content in Table 5 as it's presented. The information content would be more accessible to the reader as a multi-panel bar chart or some other graphical format. Also, it's unclear what exactly the numbers in the "Measurement" column represent.

We now include Figure 6: Scatter plot of the simulated isoprene emissions against measurements from the global above-canopy flux database sorted by ecosystem type (Table 5). We do retain Table 5 in the paper because we would like readers to have full access to the database and model data values. The measurement data is a collation of above canopy flux measurements on the plot-scale, canopy-scale and landscape-scale. We did not have information on the scale for all sites so have not included it.

7. The Guenther et al. references could be updated to include the most recent (2012) paper in GMD.

Fixed.

8. 17740, last line, "average diurnal average"?

Fixed: "average diurnal **cycle**".

References

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