May 15, 2015

Response to referee comments on "Uncertainties in isoprene photochemistry and emissions: implications for the oxidative capacity of past and present atmospheres and for trends in climate forcing agents".

We thank the reviewer for his/her valuable comments and suggestions. His/her input has significantly improved the manuscript.

Referee's comments are *in italics*, our responses are in plain text, and changes to the manuscript are in blue. (Note: all page and line references are for the "acpd-15-2197-2015.pdf" manuscript version.)

REFEREE #1

General comments

It is evident throughout the text that the authors do not fully understand the IPCC concept of global radiative forcing.

The reviewer makes a good point that we did not clearly define the term 'radiative forcing' as used here. We address this issue in the revised text. Please see below under specific comments 2, 5-6.

Based on the comparisons in Section 3.2, readers would appreciate the addition of some clear and transparent statements in the Discussion Section on which model configuration is the most realistic, especially given the large number of sensitivity simulations.

We acknowledge that readers would appreciate pointers to the most realistic model, but we are reluctant to do so. As explained in the Discussion Section, our knowledge of both isoprene photochemistry and the CO_2-sensitivity of plant isoprene emissions is still evolving. The primary focus of our study is therefore to demonstrate the range of uncertainties in model estimates arising from such uncertainties. However, we now make clear that the C1 photochemical scheme is likely outdated (page 2224, line 16):

The primary goal of this model study is to explore the sensitivity of the oxidative capacity of present and past atmospheres to assumptions about isoprene emissions and the fate of its oxidation products. We are reluctant to offer "best guess" estimates in large part because the uncertainty in the CO_2-isoprene interaction is substantial and our knowledge of the photochemical cascade of isoprene oxidation is still evolving. Some studies have suggested that canopy-scale processes may complement or offset the leaf-scale response to atmospheric CO_2 levels (e.g., Sun et al., 2013). Also, it is likely that the application of the same CO_2-sensitivity parameterization to all PFTs leads to an overestimate of this effect. As discussed below, observations of the relevant chemical species that could constrain the oxidative capacity of past atmospheres are sparse. Laboratory and field measurements, however, strongly suggest that the C1 chemistry scheme is an inadequate representation of the isoprene photochemical cascade (Paulot et al., 2009a, b; Mao et al., 2013c). Therefore, model studies that depend on a simple, C1-like isoprene photo-oxidation scheme are likely outdated, particularly with respect to their ability to accurately simulate the tropospheric oxidative capacity. All of the models participating in the ACCMIP study

in support of the IPCC AR5 used a C1-like isoprene photo-oxidation mechanism (Naik et al., 2013). Our results demonstrate that even under identical emission scenarios, the original and new isoprene photo-oxidation mechanisms yield different interpretations of various parameters such as changes in global mean OH and methane lifetime across the preindustrial-present day transition.

A further weakness of the study is that it stops at global burden changes and does not calculate radiative forcings, which may explain the authors' lack of understanding of the radiative forcing concept.

Radiative forcing calculations are beyond the scope of this work. The primary focus of our study is to explore the resulting uncertainties in tropospheric chemical composition. Therefore, our computational priorities are on chemical complexity. Because oxidants affect the abundance of climate forcing agents, we also discuss the implications of our findings for these species.

I recommend publication once the following major issues have been adequately addressed:

Major comments

1. A major concern is that ozone is treated as an oxidant and completely ignored as a climate forcing agent. The ozone results are some of the most interesting because the global burden is relatively insensitive to the isoprene emission CO_2-sensitivity and chemical mechanisms (as shown in Figure 2(b)). Yet the ozone burden increases dramatically by a factor of 2 across the cold to warm climate states. From my perspective, this result is critical. Ozone deserves a climate forcing section in the paper in its own right like methane and SOA.

The reviewer raises a good point and we have added a section on ozone (new Results section 3.5) as follows:

3.5 Implications for tropospheric ozone and radiative forcing

Isoprene and its oxidation products influence the formation and loss of tropospheric ozone (Beerling et al., 2007). As in Murray et al. (2014), we find decreasing tropospheric mean ozone burdens in each progressively colder scenario for each combination of isoprene photochemistry and emissions scenarios. The "best estimate" scenarios of Murray et al. (2014) – represented by our "C1-wo" simulations – suggest that relative to the preindustrial, the tropospheric mean ozone burden is 33% higher in the present, 27% lower at the warm LGM, and 19% lower at the cold LGM. These values do not vary more than 8% for the present day and 5% for the LGM when the isoprene photochemistry and/or emission schemes are varied.

Using the multi-model estimate of 0.042 W m^{-2} per DU change in the mean tropospheric column ozone across the preindustrial-present day transition (Stevenson et al., 2013), we estimate that across our sensitivity simulations, changes in the mean tropospheric column ozone relative to their respective preindustrial scenarios lead to forcing contributions of +0.3 W m^{-2} for the present day. If we extrapolate this relationship to the LGM-preindustrial transition, we estimate values of -0.3 W m^{-2} for the warm LGM and -0.2 W m^{-2} for the cold LGM. However, accurate quantification

of the tropospheric ozone forcing at the LGM relative to the preindustrial would require the use of an online radiative transfer model that convolves changes in the ozone distribution with other radiatively active climate processes.

We have added a discussion of the implications of the above results in our Discussion section (page 2223, line 29):

Unlike SOA, we find that changes in tropospheric mean ozone burdens relative to the preindustrial are insensitive to the uncertainties in isoprene emissions and photochemistry tested in this study. Relative to the preindustrial, the absolute magnitude of the radiative forcing from the change in tropospheric ozone at the LGM may be comparable to that of the present day. However, most climate simulations of the LGM still use preindustrial ozone values as boundary conditions, including this study and the Paleoclimate Modelling Intercomparison Project 2 (PMIP2, Braconnot et al., 2012). Accurate quantification of the tropospheric ozone forcing at the LGM relative to the preindustrial requires the use of an online radiative transfer model that convolves changes in the ozone distribution with other radiatively active climate processes.

2a. The authors misunderstand the IPCC radiative forcing concept. Page 2224: "Our work demonstrates that besides changes in land use, changes in environmental factors controlling biogenic VOC emissions should also be included in calculations of the net radiative forcing. For example, Unger (2014) reported a decrease in biogenic VOC emissions of 37% due to expanding cropland, but did not include the effects of meteorological variables or CO_2-sensitivity on such emissions. In our study, biogenic VOC emissions decrease by just 8% in the present day relative to the preindustrial due to changing meteorology and land use change, and by 25% when the CO_2-sensitivity of isoprene emissions is also considered."

The experimental design in Unger (2014) was chosen to correspond exactly to that adopted in the IPCC Fifth Assessment Report (AR5) Chapter 8: Anthropogenic and Natural Radiative Forcing (Myhre et al., 2013). Importantly, the IPCC definition of global radiative forcing refers to a single perturbation in the climate system. Unger (2014) targets the historical cropland expansion as the single perturbation. The major advantage of adopting the IPCC experimental design is that the global radiative forcing values provided in Unger (2014) are fully consistent with the IPCC AR5 value for the surface albedo change due to land use (Myhre et al., 2013). A departure from the IPCC definition is required to account for the effects of multiple human perturbations on the BVOC global radiative forcing (for instance, when incorporating the effects of anthropogenic CO_2 and physical climate change on the plant emissions, and simultaneous changes to anthropogenic pollution emissions). This alternative approach has already been published in a recent related study (Unger, On the role of plant volatiles in anthropogenic global climate change, GRL, 2014b).

The authors should be aware that several research groups (in addition to Unger, 2014a,b) have been thinking and writing about the complex issues around how to tackle the human-induced radiative impacts of BVOC emissions and photochemistry changes. For instance, see also Heald et al., Contrasting the direct radiative effect

and direct radiative forcing of aerosols, ACP, 2014; and Heald and Spracklen, Land use change impacts on air quality and climate, in press, 2015.

The reviewer raises an important point. To avoid confusion, we have clarified all text on radiative forcing and our discussion on page 2224, and we have added the two new references suggested by the reviewer. Please see the revised text in blue on page 5.

2b. What is more relevant and needed here in this work in the Discussion Section is a comparison of your results to those of the previous 3 IPCC-class vegetation-climate models for the preindustrial to present day change in isoprene that isolate the roles of individual global change drivers. You have included 2 of these already on Page 2207: "Previous studies, which employ different global biogenic VOC emission models and land cover products to the ones used in this study, find that biogenic VOC emissions were 20–26% higher in the preindustrial relative to the present day (Pacifico et al., 2012; Unger, 2013). In this study, we estimate this value to be 8% when the CO_2-sensitivity of plant isoprene emissions is not considered, and 25% when the CO_2-sensitivity is considered." Another important result to include is Lathiere et al., Sensitivity of isoprene emissions from the terrestrial biosphere to 20th century changes in atmospheric CO_2 concentration, climate, and land use GBC, 2010. This study uses MEGAN isoprene emission algorithms embedded in ORCHIDEE.

We now refer to Lathiere et al. (2010) in our study.

Your result is consistent with these 3 IPCC-class models for the net change in isoprene emissions (~25% decrease between preindustrial and present day) but the ICECAP model framework obtains the result for a different reason. In the 3 IPCC-class models, the historical human land cover change is the dominant driver of the reduction, whereas in your model framework the CO_2-sensitivity effect is the dominant driver of the reduction. Can you explain this difference? (See Point (3) below about over-estimate of CO_2-sensitivity in global models). I recommend to check the basal isoprene emission factors in your model and the vegetation cover change fractions between the PI and PD. How does LAI change in your model in the different climate states? Are you over-estimating LAI changes?

The reviewer raises good questions. In fact, Lathiere et al. (2010) found that the CO_2-sensitivity effect dominates the change in isoprene emissions between 1901-2002, with the impact of land use change about half that of the CO_2-sensitivity: rising atmospheric CO_2 levels reduce isoprene emissions over this time period by 21% and cropland expansion by 10%; climate change offsets these reductions by increasing isoprene emissions by 7% (Lathiere et al., 2010).

We now clarify that the basal isoprene emission factors per plant functional type used in our model do not change between any of the climate scenarios (Murray et al., 2014, Table 5). Isoprene emissions here respond to shifts in: (1) LAI and the distribution of PFTs as output by the BIOME4-TG equilibrium vegetation model in response to climate; (2) prescribed cropland extent; (3) temperature, PAR, etc., as it affects the MEGAN BVOC emission parameterization; and (4) atmospheric CO_2 levels (only for the "with" CO_2-sensitivity simulations). Differences in the dominant factor driving the modeled decrease in global isoprene emissions among the four studies are most likely due to differences in the time periods of the simulations, land use trends

applied, changes in LAI and the distribution of PFTs, and the CO_2-sensitivity algorithm considered in each study. These differences are summarized in the table below.

	Time periodof simulation	**PI-to-PD change in crop cover (%)**	**PI-to-PD change in CO_2 (%)**	**Reference for CO_2-sensitivity algorithm**
This study	1770s-1990s	+10	+32	Possell & Hewitt, 2011
Lathiere et al. (2010)	1901-2002	?	+27	Possell et al., 2005
Pacifico et al. (2012)	1860-2000	+7	+29	Arneth et al., 2007
Unger (2013)	1880-2000	+22	+27	Wilkinson et al., 2009; Heald et al., 2009

The Possell and Hewitt (2011) scheme for CO_2-sensitivity of isoprene emissions likely represents an upper limit of this effect.

We have added a more detailed comparison based on the reviewer's recommendation. In response to all of the issues raised in the reviewer's comments 2a and 2b, the discussion section on Page 2224, line 1, now reads:

Besides SOA, changes in biogenic VOC emissions also affect the atmospheric concentrations of other climate forcing agents. Recent studies have demonstrated the importance of considering the net effect of human-induced changes in biogenic VOC emissions on global climate forcing over the industrial period (e.g., Unger, 2014a, b; Heald et al., 2014; Heald and Spracklen, 2015). Unger (2014a) quantified the global radiative impact of changes to the atmospheric concentrations of ozone, methane, and SOA due to a reduction in the emission of biogenic VOCs resulting from global cropland expansion between the 1850s and 2000s. She estimated a net cooling of -0.11 ± 0.17 W m^{-2}, which is comparable in magnitude but opposite in sign to the net forcing from the changes in surface albedo and land carbon release associated with cropland expansion. When other known anthropogenic influences on biogenic VOC emissions are also considered, the net global climate forcing is estimated to be -0.17 W m^{-2} (Unger 2014b). Our work demonstrates that reducing the uncertainties on such an estimate will require improvements in our knowledge of isoprene photochemistry and CO_2-sensitivity, as well as reconciling model estimates of land cover change over the industrial period.

We find that biogenic VOC emissions decrease by 8% in the present day relative to the preindustrial due to changing meteorology, redistribution of natural vegetation, and cropland expansion, and by 25% when the CO_2-sensitivity of isoprene emissions is also considered. The larger reduction is comparable to results from previous studies that have estimated a 20-26% reduction in biogenic VOC emissions from the late 19th century to the present day (Lathiere et al., 2010; Pacifico et al., 2012; Unger, 2013). Consistent with our study, Lathiere et al. (2010) determined that the CO_2-sensitivity effect dominates the change in isoprene emissions between 1901-2002, with the impact of land use change about half that of CO_2-sensitivity. In contrast, Pacifico et al. (2012) and Unger (2013) found cropland expansion to be the dominant driver of

the reduction. This discrepancy likely arises for two reasons. First, our study applied an increase of approximately 10% in global cropland expansion (Guenther et al., 2012), which is smaller than the 22% change estimated by Unger (2013). Second, we apply a CO_2-sensitivity algorithm that most likely provides an upper limit of this effect for past climates (Possell and Hewitt, 2011).

Addition to section 2.2 (page 2205, line 10):

...into GEOS-Chem. The basal biogenic emission factors per plant functional types used in the BIOME4-TG model, which do not change between the climate scenarios, can be found in Murray et al. (2014), Table 5.

3. One of the main strengths of the study, and most interesting aspects, is testing the impacts of the isoprene CO_2-sensitivity parameterization by doing simulations with and without this effect. The CO_2-sensitivity parameterization is likely drastically too strong in current global models (including the one used in this study) in part because it has been applied uniformly to all PFTs. The "null" response is not typically reported in the plant physiology literature. Furthermore, some studies report increases in isoprene emission at high CO_2 (e.g. Sun et al., 2013).

We acknowledge in section 2.2 that the CO_2-sensitivity parameterization employed in our study most likely provides an upper limit of this effect for past climates, and in the Discussion section that our knowledge on this issue is still very much evolving. As stated in the original text, we chose the Possell and Hewitt (2011) parameterization because it is based on the widest range of plant taxa (page 2206, lines 20-24). As suggested by the reviewer, we now also discuss how uniform application of the CO_2-sensitivity to all PFTs will likely contribute to the overestimate (page 2224, line 22):

Also, it is likely that the application of the same CO_2-sensitivity parameterization to all PFTs leads to an overestimate of this effect.

We thank the reviewer for pointing out the Sun et al. (2013) study. They found increased isoprene emissions at high CO_2, which suggest that canopy-scale dynamics may offset leaf-scale processes, but did not perform any experiments at CO_2 levels relevant for our study (i.e., below 380 ppm). We have included this reference in our Discussion (page 2224, line 22):

Some studies have also suggested that canopy-scale processes may complement or offset the leaf-scale response to atmospheric CO_2 levels (e.g., Sun et al., 2013).

4. How are other plant terpenoid emissions treated in this study? Monoterpenes? Is CO_2-sensitivity applied to their emissions?

The CO_2-sensitivity has only been applied to plant isoprene emissions because its effect on other plant VOC emissions is less conclusive, with most studies observing no significant effect on monoterpene and sesquiterpene emitting species [Penuelas and Staudt, 2010]. Moreover, isoprene emissions constitute over 60% of total plant VOC emissions in all four climate scenarios (Murray et al., 2014, Figure 5). We have added a comment about this issue in Section 2.2 (page 2206, line 24).

We have not considered the effect of CO_2-sensitivity on other plant VOC emissions, such as monoterpenes and sesquiterpenes, due to lack of conclusive evidence of this effect (Penuelas and Staudt, 2010). In all four climate scenarios, isoprene constitutes more than 60% of total biogenic VOC emissions.

5. Misunderstanding radiative forcing again. Page 2202: "Uncertainties in the preindustrial-to-present day changes in biogenic SOA burdens lead to large uncertainties in the anthropogenic direct and indirect radiative forcing estimates (e.g., Scott et al., 2014; Unger, 2014)."

Authors need to be careful here. Scott et al. computes the present-day radiative effect of biogenic SOA (with and without SOA in the present-day atmosphere). Their result does not assess any human impacts on the biogenic SOA global radiative effect. In contrast, Unger computes the effects of the anthropogenic historical cropland expansion on biogenic SOA (i.e. an anthropogenic radiative forcing mechanism). Another more recent paper computes the effects of all anthropogenic influences on BVOC emissions and photochemistry between 1850s and 2000s and provides a biogenic SOA radiative forcing estimate (Unger, On the role of plant volatiles in anthropogenic global climate change, GRL, 2014b).

We acknowledge that we should have been more careful with our wording as well as our choice of references here. We have clarified all text on radiative forcing and climate impacts. We reference Carslaw et al. (2013) based on their statement that "Our results show that 45 per cent of the variance of aerosol forcing since about 1750 arises from uncertainties in natural emissions of volcanic sulphur dioxide, marine dimethylsulphide, biogenic volatile organic carbon, biomass burning and sea spray". We reference Scott et al. (2014) based on their statement that "the anthropogenic indirect radiative forcing between 1750 and the present day is sensitive to assumptions about the amount and role of biogenic SOA." This section now reads (page 2201, line 26):

The oxidation products of isoprene also substantially contribute to secondary organic aerosol (SOA) formation (Henze and Seinfeld, 2006). Biogenic SOA, like other aerosols, affects climate by scattering and absorbing solar radiation and by altering the properties and lifetimes of clouds, but the net climate effect is poorly characterized (Scott et al., 2014). Therefore, uncertainties in the preindustrial-to-present day changes in biogenic VOC emissions, and subsequently in SOA burdens, lead to large uncertainties in the anthropogenic indirect radiative forcing estimates over the industrial period (e.g., Carslaw et al., 2013; Scott et al., 2014).

We now reference Unger (2014a, b) in our Discussion section. Please see our response to comment #2 above.

6. Misunderstanding radiative forcing again. Page 2223: "The climate effects of biogenic SOA are not well characterized, but are thought to provide regional cooling (Scott et al., 2014)."

I could not find any scientific evidence being presented in Scott et al. (2014) that biogenic SOA plays a role in regional cooling. The Scott et al. (2014) paper

investigates the global direct and indirect radiative effects of biogenic SOA in the present day (with and without SOA) with a particular emphasis on the possible contributions from new particle formation.

We thank the reviewer for pointing this out and have inserted new references here. This section now reads (page 2223 line 22):

The climate effects of biogenic SOA are not well characterized, but previous studies have estimated the regional direct radiative effect from biogenic SOA to be cooling (e.g., Lihavainen et al., 2009; Rap et al., 2013). Our work thus suggests that SOA reductions may have amplified regional warming in the present but minimized regional cooling at the LGM, relative to the preindustrial. Results from our sensitivity studies, however, underscore the large uncertainties in current model estimates of the anthropogenic indirect radiative forcing over the industrial period (e.g., Carslaw et al., 2013; Scott et al., 2014).

7. Why was the soil moisture dependence not included for isoprene emissions? Please explain.

Investigating the soil moisture dependence, although important, is beyond the scope of our present study, as the effect is still highly uncertain for biogenic isoprene emissions (Huang et al., 2015). This method also allows us to be as consistent as possible with Murray et al. (2014) in terms of model setup besides the parameters being investigated, as our primary goal is to isolate the sensitivity of model estimates to the CO_2-sensitivity algorithm. In MEGAN, environmental factors such as atmospheric CO_2 concentration and soil moisture are treated as scaling factors of the base emission rates (Section 2.2). Therefore, the relative differences with and without consideration of the CO_2-sensitivity are unlikely to change whether or not soil moisture dependence is considered.

8. Does this model account for changes in stratospheric ozone due to the different greenhouse gas concentrations? It is well established that stratospheric ozone increases with higher greenhouse gas levels due to the colder stratosphere that reduces the rates of the chemical destruction reactions (e.g. Waugh et al., 2009 and many others), which will have large implications for the stratosphere-troposphere exchange calculations as well as the tropospheric photolysis rate calculations.

Yes, the model accounts for chemical as well as dynamic changes in stratospheric ozone. As explained in the original manuscript (page 2203, line 22 and page 2221, line 17), "The ICECAP project is the first 3-D model framework to consider the full suite of key factors controlling the oxidative capacity of the troposphere at and since the LGM, including the effect of changes in the stratospheric column ozone on tropospheric photolysis rates." Murray et al. (2014) found that "reductions in greenhouse gases… decelerate the stratospheric residual circulation, … [leading to] an increase in tropical stratospheric ozone columns.") The GEOS-Chem model also includes online linearized stratospheric chemistry (McLinden et al., 2000). We have added this comment in section 2.1 (page 2204, line 17):

GEOS-Chem is a global 3-D chemical transport model (CTM) with a long history in simulating present-day tropospheric ozone-NO_x-CO-VOC-BrO_x-aerosol chemistry

(http://www.goes-chem.org; Bey et al., 2001; Park et al., 2004; Parrella et al., 2012). The version used here includes online linearized stratospheric chemistry (McLinden et al., 2000), which allows for calculation of photolysis rates more consistent with changing climate and chemical conditions.

9a. Technical issues. The simulations are performed using only one year of archived meteorology for each time slice. Therefore, no assessment can be provided of uncertainty due to internal climate variability with this model framework.

As in Murray et al. (2014), we use four subsequent years of archived meteorology for each time slice. We have clarified this in the method section as follows (page 2209, line 5):

For each scenario, we use four subsequent years of archived meteorology from the GISS climate model. Each GEOS-Chem simulation is initialized with a 10-year spin-up, repeatedly using the first year of archived meteorology, to reach equilibrium with respect to stratosphere-troposphere exchange. We then perform three more years of simulations for analysis, using the three subsequent years of archived meteorology. All of the quantities considered here are global means or averages over large spatial regions. We find that the inter-annual variability of such quantities is small compared to the differences between the scenarios, and that three years is sufficient for our analysis.

9b. The AR4 GISS ModelE version is about 10 years old and at coarse spatial resolution (4°×5°; 23 vertical layers). Has the stratospheric-tropospheric exchange been captured properly in the framework, also given that only one year of meteorology is applied to calculate it?

We analyze three years of GEOS-Chem output. Please see our response to Comment 9a. Evaluation of the simulated stratosphere-troposphere exchange in ICECAP is discussed in Murray et al. (2014), section 2.5 and supplement. We have added a brief discussion to page 2205, line 14:

The ICECAP model overestimates transport from the stratosphere due to an overly vigorous Brewer-Dobson circulation (Murray et al., 2014). Rather than fixing the transport fluxes to better match present-day values, we accept this bias in order to allow the stratospheric columns of ozone to adjust freely to different climate scenarios. For example, Murray et al. (2014) found that reductions in greenhouse gases weakens the stratospheric residual circulation and leads to an increase in tropical stratospheric ozone columns.

10. Page 2208: "in which HO_2 uptake yields H_2O via coupling of Cu(I) /Cu(II) and Fe(II) / Fe(III) ions". How do we know about metal ions in the LGM and PI? Are they related to the dust distribution?

The reviewer raises a good point. Cu and Fe are ubiquitous components of crustal and combustion aerosols (Mao et al., 2013a) and are related to the dust distribution and volcanic activity. We have added the following information to the Introduction (page 2203, line 11):

Cu and Fe are ubiquitous components of crustal and combustion aerosols (Mao et al., 2013a). Observations and model studies suggest that during the LGM and preindustrial, natural dust distributions were higher than that in the present day (Mahowald et al., 2006). In particular, during the LGM, Fe(II) and Fe(III) ion concentrations in dust increased by at least two times relative to interglacial levels (Spolaor et al., 2013). Likewise, positive Cu anomalies during the last glacial period have been measured in ice cores (Oyarzun et al., 2005).

11. Table 1. That the global isoprene source from terrestrial ecosystems could be 50% higher in the LGM (when the temperate zone was covered in ice) compared to present day conflicts with common sense about the global Earth system plant productivity and behavior. Can you offer an explanation and justification?

Yes, this result is surprising. We have added an explanation to the Discussion section (page 2222, line 11). Note that we compare the LGM value with the preindustrial (rather than the present day) to match our practice for the rest of the paper, but the same reasoning applies.

This implementation increases global isoprene emissions in the warm LGM scenario by 15% relative to the preindustrial. At the LGM, lower sea levels expose extensive land area in equatorial Asia and Australia, which leads, in turn, to large regional increases in plant isoprene emissions (Murray et al., 2014, Figure 7). When we account for the potential increase in biogenic isoprene emissions at low CO_2 concentrations, this implementation swamps the effect of cooler temperatures in the warm LGM scenario.

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