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Interactive Comment

Interactive comment on "Influence of future climate and cropland expansion on isoprene emissions and tropospheric ozone" *by* O. J. Squire et al.

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Note: Red text is that which will be added in.

1 Reviewer 1's Comments

We thank Reviewer 1 for taking the time to read and comment on the paper. Comments and criticisms have been duly noted and our detailed replies are below.

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1.1 Major criticism - the use of different scenarios for different parameters.

As we made clear in our Interactive Comment on 18 July, while we understand the referee's comments about our scenario choices, we fundamentally disagree. First, we are not trying to 'predict' a particular future state of the atmosphere but rather to explore the possible interactions that are consequent on different choices (and hence scenarios). We have modified our language in a number of places to make this clearer (and see the first bullet, immediately below). Second, we argued in our earlier response that any inconsistency between scenarios would not crucially affect our objectives. Our proposed paragraph about near-linearity (see second bullet, below) further emphasizes that point.

- Throughout the text we will make alterations to emphasize the fact that our calculations should not be seen as predictions, but as what *could* happen to tropospheric composition over the 21st century under the given assumptions.

- p18316 l3, new paragraph: "We show later (see section 4.2 and Fig. 5) that, although the magnitude of changes in tropospheric O3 could vary with the factors investigated here, the effect of the different factors (climate, isoprene emissions, etc) on O3 is approximately linear. So, an integration containing future climate, isoprene emissions and anthropogenic emissions produces a very similar O3 change to the sum of three separate integrations where each parameter is changed in turn. For this reason, although the use of different scenarios would likely lead to a somewhat different magnitude of future calculated O3, it is unlikely that the choice of scenario could move the model into an entirely different regime of O3 production, and with a substantially altered O3 response."

- p18318 l12: The following sentence will be added to emphasize the uncer-

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tainty associated with calculating possible future isoprene emission changes: "It is important to note though that as calculating future global isoprene emission changes involves a number of terms, each of which is uncertain, the overall balance between these terms has a high degree of uncertainty."

1.2 Abstract: should specify that both anthropogenic and natural land use change are included in the analysis

In the abstract on p18308 l10 we will change the text to: "...changes in isoprene emissions caused by changes in climate (including natural land use changes), anthropogenic land use, and the inhibition of isoprene emissions by CO2..."

1.3 Section 2.1: Is the SDGVM run continuously (from 2000 to 2095) or in time slices?

The SDGVM was run in two time-slices, one for present day (2000) and one for future (2095). Each time the model was run until vegetative equilibrium, and then the BVOC emissions were calculated.

In Sect. 2.1 starting p18312 l25 we will change the text to: "...In all cases first the vegetation distribution was determined using the Sheffield Dynamic Global Vegetation Model (SDGVM) (Beerling et al., 1997; Beerling and Woodward, 2001) . The model was run in time-slices, for present day (2000) and future (2095) conditions, each time being run to vegetative equilibrium. The SDGVM calculates the potential distribution and..."

1.4 Section 2.2: How does CO2 fertilisation impact the LAI? + Section 2.2: Figure 1 suggests that the SDGVM does not predict an expansion of broadleaf trees northwards with future climate. Why?

Although the SDGVM calculates the impact of climate (including CO2-fertilisation) on the LAI and distribution of PFTs, these are only used to calculate isoprene emissions, and not fed into the UM-UKCA runs directly. The only changes in LAI/PFTs included in the UM-UKCA runs are those resulting from future cropland expansion as calculated by the IMAGE model (only included in the land use change runs). It is these changes that are shown in Figure 1. Since Figure 1 only shows the change in LSTs with anthropogenic land use change (specifically cropland expansion), there is no northward expansion of broadleaf trees as might be expected with climate change.

To highlight that Figure 1 is specifically showing the change in LSTs with anthropogenic land use, this will be specified in the Figure caption: "...between present day (2000) and the anthropogenic land use scenario (cropland expansion) for 2095 (2095 - 2000)..."

1.5 Section 2.2: What was the total increase in crop area? (in both absolute and percentage values)

Total increase in crop area is 6.34×10^{12} m^2 (an increase of 135%).

In Sect. 2.2 p18314 l9 we will change the text to: "The IMAGE model calculated an increase in croplands by 2095 of 6.34×10^{12} m^2 (135%), which corresponds to an increase in the fraction of C3 grasses in UM-UKCA as shown in..."

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1.6 Section 3: The authors suggest that their simulated climate impact (both T and CO2 fertilisation) on isoprene emissions (+78 Tg/yr) is similar to several studies. While the sign (i.e. an increase) is the same, the values are substantially different (factor of 2-4 less) than previous studies (eg. Young et al., 2009; Heald et al., 2009, both 13, C4893–C4895, 2013 cited). Given these differences, which appear to be associated with the Amazonian die-back mentioned, it would be useful to separate the T effect and the CO2 fertlisation (or natural land use change) effect. In this way the authors could more meaningfully compare the first and contrast the second with previous studies.

We would argue that the comparison of isoprene emissions made here is meaningful. The integrations we are comparing to in all of the studies (Sanderson et al., 2003; Lathiere et al., 2005; Arneth et al., 2007, Heald et al., 2009, Young et al., 2009) include both the temperature and CO2-fertilisation effects of climate change in a single integration as done here.

Comparing our climate change integration with the most similar integration in each of the above studies (present day ~2000, future ~2100, including both temperature and CO2-fertilisation effects) our value of +17% (+78 Tg C yr^{-1}) shows a similar percent increase to Sanderson et al., (2003) (+21%), Lathiere et al., (2005) (+27%) and Wu et al., (2012) (+25%). The three other studies calculate significantly higher values. As discussed in Sect. 3 the main cause of the discrepancy is the degree to which, in isoprene-emitting regions, models simulate a die-back of vegetation associated with a decrease in soil moisture under the elevated temperatures of climate change.

We will change the text in the paragraph starting p18316 l16 as follows:

"Figure 2c shows the difference in isoprene emissions caused by climate change. Globally we find that climate change (which includes both changes in temperature

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and CO2-fertilisation) increases isoprene emissions by 78 Tg C yr^{-1} (17%). This increase is expected for the higher temperatures and CO2 levels in 2095 which directly stimulate isoprene emissions and extend fertilisation of the biosphere respectively. A number of studies that also include both temperature and CO2-fertilisation effects similarly calculate an increase in total global isoprene emissions with climate change over the 21st century (Sanderson et al., 2003; Lathiere et al., 2005; Arneth et al., 2007; Heald et al., 2009; Young et al., 2009), but the magnitude of the increase varies considerably between studies. Four studies (this present study (+17%, +78 Tg C yr^{-1}), Sanderson et al., (2003) (+21%, +131 Tg C yr^{-1}), Lathiere et al., (2005) (+27%, +136 Tg C yr^{-1}) and Wu et al., (2012) (+25%, +103 Tg C yr^{-1})) calculate moderate increases. The three other studies calculate significantly higher values. The main source of discrepancy is the extent to which, in certain regions, models simulate a die-back of isoprene emitting vegetation associated with a decrease in soil moisture under the elevated temperatures of climate change. In this current study, although isoprene emissions increase overall, this die-back is calculated in areas such as the Amazon and parts of the Maritime continent. Such effects have been calculated in previous studies (Cox et al., (2000); Sanderson et al., (2003); Lathiere et al., (2005). In some other studies 2100 soil moisture is high enough to avoid large scale die-back, and subsequently their calculated increases in isoprene emissions are much higher (e.g. Heald et al. (2009) calculate increases of 1344 Tg C yr^{-1} (265%)).”

1.7 Page 18317, line 17: Close to a factor of 3 hardly seems “slightly greater”. I suggest this be reworded.

The text on p18317 l16 will be reworded to highlight that there is significant difference between the results in our study and in that of Wu et al. (2012) and reasons for possible discrepancy will be given: “Wu et al. (2012) also calculate that future land use following the A1B scenario causes a decrease in end of 21st century isoprene

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emissions compared to the future case with present day land use. However they calculate a smaller decrease of only -67 Tg C yr^{-1} globally. The use of a different vegetation model (LPJ-DGVM) is a potential source of discrepancy."

1.8 Page 18318, lines 9-12: This is only true if the land use scenario projects an overall decrease of vegetation cover and LAI for isoprene emitters.

We will change the text on p18318 l10 as follows: "Assuming, as in our study, that the land use scenario projects an overall decrease in isoprene emitters, it follows that the combined effect of both land use change and CO2 inhibition should lead to a decrease in global isoprene emissions as found here."

2 Reviewer 2's Comments

We thank Reviewer 2 for the positive comments and note particularly that he/she supports our methodology and agrees that our choice of scenarios is unlikely to alter the conclusions of this sensitivity study.

2.1 Section 2.1: I am concerned that the isoprene emissions were calculated as a function of either grasses or trees. How are shrublands and wooded savannas considered here? Are they treated as forests?

No special vegetation type is included here to represent specifically shrublands or savannas. In these simulations we calculated emissions from the dominant PFTs for the major biomes of the world. Shrubs rarely fall into this category, although as understorey plants they can contribute to emissions, but this effect is neglected in our work. The BVOC emissions model only includes those PFTs used in the SDGVM. VOC emissions from shrublands and savannas were therefore modelled using the simulated distribution of a mixture of trees and grasses.

2.2 In Section 2.2., it is also stated that the remaining LSTs, which do not appear in the SDGVM, are adapted from their present-day values to account for cropland expansion. This is a bit confusing to me. Do the SDGVM PFTs cover the entire land area of the globe?

The LSTs in question here are those in UM-UKCA. The LSTs in UM-UKCA that do not appear in the SDGVM are shrubs, urban and ice (note: urban and ice are considered as bare soil in the SDGVM). As they are not in the SDGVM there is no way of knowing how their distribution will change with cropland expansion. As such, we make an approximation that in a gridcell where crops increased by a given percentage x (according to our IMAGE model calculations), these LSTs decrease by x% from their values in the present day UM-UKCA run.

2.3 How are the emissions of shrublands and in urban areas assigned?

See the answers to comments 2.1 and 2.2. In urban areas BVOC emissions are very small compared to emissions of other VOCs and NOx, which, as mentioned in section 2.3, were taken from the Edgar 3.2 dataset (Olivier and Berdowski, 2001) for present day, and following the B2+CLE scenario for 2095.

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2.4 In the sections explaining the results, I think it would be interesting to not only include the absolute changes, but also the % change in ozone concentrations and burdens. (This is done with isoprene, e.g., the 55% reduction in emissions when all changes are included). For example, on page 18323 (lines 27-29), how substantial are 9ppb increases in ozone relative to the base case?

We will add percentages in Sect. 4.2 and beyond and in Table 2.

2.5 On that same section, the authors find more than 10 ppb decreases in ozone over the eastern US; this is attributed to changes in anthropogenic emissions in that area. How does this compare to other studies? If using a different emissions scenario, how would the results differ?

In our study, we use the B2+CLE scenario which is characterised by large emission cuts across the industrialised regions of the northern hemisphere (Eastern USA, Japan and Europe). These emission cuts are the driver of the large decreases in O3 in these regions. Indeed, if a different scenario is followed, the effect of anthropogenic emissions on O3 can vary significantly. For example, Zeng et al. (2008) use the A2 ("business as usual") SRES scenario, and do not find these northern hemisphere O3 decreases. In fact the major surface O3 feature are increases over China/India of up to 40 ppb.

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2.6 Page 18316-18318: Although the Figure 2 is included, a table summarizing the results in isoprene emission estimates (described in Section 3) would be helpful.

As the changes in global isoprene emissions are stated in Figure 2, it isn't clear what including the same information in Table format would add to the paper. As such, we would prefer not to include the extra table.

2.7 An editorial note: throughout the paper, the authors use "which" as a nonrestrictive clause. In this case, there should be a comma preceding the "which". If it is a restrictive clause, then "that" should be used instead of "which", and no comma should be used. I recommend that the authors go through the paper to ensure that these words are used properly, and are properly punctuated.

We thank the author for pointing this out, and this will be corrected throughout the text.

2.8 Page 18314, line 7: "as detailed below" can be removed (or changed to "as detailed here"?)

We will remove the sentence containing this phrase, and reword the last sentence of the paragraph (p18314 l16) to account for this: "The fraction of needle-leaved trees and C4 grasses also decreased (lumped into 'Other' - Figure 1d), as did those LSTs not included in the SDGVM. These LSTs were adapted from their present day UM-UKCA values to account for cropland expansion such that in a gridcell where crops increased by a given percentage x, each LST was decreased by x%."

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