Interactive comment on "Ozone vegetation damage effects on gross primary productivity in the United States" by X. Yue and N. Unger

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We thank Dr. Felzer for the positive and helpful comments that have improved the manuscript. Detailed point-by-point responses to the reviewer comments are provided below. The reviewers' comments are shown in italics with our responses embedded using regular font text. The page and line numbers below refer to the revised manuscript submission version.

*Ozone vegetation damage effects on gross primary productivity in the United States by Yue and Unger adds the effects of ozone to a vegetation model to explore the effect of ozone on U.S. GPP during 1998-2007. I particularly like the attempt to validate the ozone effect on photosynthesis against previously measured values (Figure 9) before extrapolating the model across the entire U.S. Comparing the model- produced ozone to EPA site data (Figure 7) is an important part of this study. They also explore the role of using the correct meteorology and phenology in determining the ozone effect. The approach is to use the CUO index and ozone uptake, following Sitch et al. (2007), which is appropriate for models at the hourly resolution. I suggest the paper be accepted after minor revisions suggested below.*

*1. Introduction, 3rd paragraph: "For example, based on . . .", should include the caveat that Lombardozzi found the effect of ozone on stomatal conductance to be much less than that on photosynthesis.*

We have added (Page 3, Lines 69-71):
"Emerging research has found that the $O_3$ vegetation damage effects may result in a loss of plant stomatal control, and a consequent decoupling of the stomatal response from photosynthesis inhibition (Lombardozzi et al., 2012a, 2012b, 2013)."

*2. Section 2.1.1: The issue of a needs to be addressed. Values for different PFTs were originally derived by Sitch et al. 2007 by regressing their MOSES model against field measurements. Is it plausible to use the same values of alpha, or do these need to be rederived for each model? The authors need to address this point, and demonstrate clearly that there is no need to redo the regression with their particular model.*

Both MOSES/JULES and YIBs models employ the almost identical Faquhar-Ball-Barry photosynthesis/stomatal conductance scheme. Thus, the response of modeled photosynthesis to ozone damage will be nearly identical in the two vegetation models at the leaf level. Consequently, it is appropriate and reasonable to apply the same alpha sensitivity parameters as those in Sitch et al. (2007) for the $O_3$ damage scheme. In the text, we clarified it as follows (Page 7, Lines 191-198):

"The parameters for the scheme, including the $O_3$ damage threshold and sensitivity coefficients, were originally derived based on the calibration of the MOSES vegetation model. Since the MOSES model employs the (almost) identical Farquhar-Ball-Berry photosynthesis/stomatal conductance scheme as in the YIBs model, it is appropriate to adopt the same parameters as those derived in Sitch et al. (2007) (Table 1). Evaluation of the YIBs simulated $O_3$-induced GPP response with available field and laboratory measurements across a range of PFTs in Section 3.4 indicates that our assumption is reasonable."

*3. Is there any sort of calibration of the vegetation model itself? If it were calibrated to specific sites with ozone, then obviously the results at validation sites would be better with ozone than without. There needs to be some description in the Methods about how the model is calibrated, and whether that is done with or without ozone. If all the parameters values are those listed in Table 1, and they are all taken from the literature (or other models), then make sure to state that.*

We have added clarification in the Methods section (Page 5, Lines 139-143):
"Appropriate photosynthesis parameters for the local vegetation type are taken from (Friend and Kiang, 2005) and the Community Land Model (Oleson et al., 2010) with updates from Bonan et al. (2011) (Table 1). In both the site-level and distributed models, we apply these model PFT-specific photosynthesis parameters and do not tune or calibrate to the local vegetation properties."

*4. Would make more sense to relable "Results" as "Results and Discussion" and "Discussion and conclusions" as "Summary and Conclusions" based on the material.*

We have removed the discussion paragraphs from the Results section and integrated the discussion into the Discussion and Conclusions section.

5. Avoid over use of "Figure 3 shows that . . ." – just refer to the figure in parentheses when discussing what it is that the figure shows.

We have changed as suggested (for Figures 1-10).

6. Missing “the” in 3.1, third paragraph (“To quantify the performance of THE vegetation model”)

Fixed (now in the third paragraph in section 2.2.1).

*7. Would help to note that there are not that many deciduous needleleaf forest or evergreen broadleaf forests in the U.S., since their model does not distinguish these, even though they are in the ISLSCP dataset.*

We added the following sentences as suggested (Page 11, Lines 316-319):
“Some of the ISLSCP land types, such as the deciduous needleleaf forest, are not represented in the YIBs model. However, the coverage of these types is very small in the U.S. (Fig. S2) and will not influence the regional simulation after the conversion to the model types.”

*8. In discussion of Figure 4, the role of ozone is not discussed, and is also barely noticeable in the figures. I would suggest either discussing it, or removing ozone from the figures because the scale of the effect is so small relative to observations and simulations with ozone. Likewise, the ozone effect is very small in Figure 6 relative to the effect of phenology, so this should be pointed out.*

We have modified Fig. 2 (original Fig. 4) to make the comparison between $O_3$-free model and observations more clear. We removed $O_3$-damaged GPP results from the figure and instead added a supplemental Fig. S4, which shows the 30-day-smoothed daily GPP. We have added Fig. S3 that shows the impact of the $O_3$-damage effect on the correlation coefficient for modeled and measured GPP. In the last paragraph of section 3.3, we add the following sentences to point out that the O3 effect is much smaller relative to the choice of phenology data (Page 16, Lines 458-462):

“The bias-correction from $O_3$ damage is much smaller relative to the effect of phenology (Fig. 4). Moreover, the $O_3$-induced damage does not improve the GPP correlation between observations and simulations, which remains similar at ~0.8 (for 40 sites) with and without $O_3$ effects (Fig. S3).”

*9. Figure 8a would be more useful if plotted with a y axis of the 8 hour maximum ozone level, since that is more closely related to ozone damage on vegetation than just the mean concentration. I would also suggest showing an additional plot here of the mean stomatal conductance for each site, as ozone uptake is determined by both the ozone levels and the stomatal conductance.*

The 8-hour maximum level may be more relevant in the concentration-approach to modeling $O_3$ plant damage. However, the YIBs model follows the uptake-approach (from Sitch et al., 2007) where the $O_3$ vegetation damage is dependent on the instantaneous [$O_3$] instead of the maximum value (see Equation 8). In addition, we have examined the $O_3$ damage effect at highly elevated [$O_3$] in Fig. 7 using our approach. Therefore, we believe that the average [$O_3$] is more relevant than the 8-hour maximum $O_3$. We added the average stomatal conductance as suggested (see revised Fig. 6b).

*10. Additional experiments discussed in section 3.3 (basis of Figure 9) and the future simulations ought to be discussed in the methods.*

We now describe the sensitivity experiments in the Methods section as suggested (see the last paragraph in section 2.2.1 and last sentence in section 2.2.2).

*11. Do the experiments in Figure 9 include any diurnal cycle of ozone, or are the values held completely steady at 20 thru 140 ppbv. If so, then I am not sure how there would be any effect on vegetation for the lower ozone values, unless stomatal conductance were unusally high.*

We clarify as follows (Page 10, Lines 300-305):
"We do not include diurnal and seasonal variations of [$O_3$] in these sensitivity simulations as that in METsite_LAImerra for two reasons. First, field measurements for the $O_3$ vegetation damage are usually performed with fixed [$O_3$] during the growth season (e.g. Ishii et al., 2004; Zhang et al., 2012). Second, the diurnal cycles and seasonality of [$O_3$] are very different for different sites (Bloomer et al., 2010), making it difficult to apply a uniform temporal cycle for all the NACP sites."

*12. There needs to be a discussion about the implications of not including nitrogen deposition. Where high ozone levels exist, there are also likely high levels of N deposition. So, while inclusion of ozone improves the model estimates (final paragraph section 3.3), including nitrogen deposition would probably more than offset the ozone effects. A separate issue to discuss in the final section is the implications of using a model that does not account for effects of N-limitation on GPP. Is that the main reason why GPP values are too large? Is the addition of ozone just correcting for this effect?*

We understand that missing of nitrogen deposition may be a source of uncertainty in our estimation of $O_3$ vegetation damage. We discuss such limitation, as well as other factors, in the revised paper as follows: "Interestingly, this mechanism would therefore provide a way to improve the simulated GPP overestimates. That said, other studies have suggested that the $O_3$ damage effect is limited by carbon-nitrogen interactions (Ollinger et al., 2002;

Kvalevag and Myhre, 2013)." (1st paragraph of section 4)

The GPP values are not always too large, as you may find that our predicted GPP is lower than observations at some sites (Fig. 2). We did not calibrate the model for $O_3$ damage purpose, since we use almost the same parameters from the Community Land Model (CLM). Most important, the $O_3$ damage to vegetation is limited in U.S. due to the low [$O_3$]. The correlations are almost identical with and without $O_3$ (Fig. S3).

*13. Is the model run illustrated in Figure 10 the one with high or low ozone?*

The result in Fig. 8 (original Fig. 10) is GPP with high $O_3$ damage. We describe in the figure caption and on the plot itself.

*14. Missing period in sentence that starts with Figure 11.*

Added as suggested for Fig. 9 (original Fig. 11) (Page 17, Lines 516-517):
"We calculate both $O_3$ stomatal flux (Fig. 8b) and the resultant damage on GPP (Fig. 9) in the U.S. region for the 1998-2007 period."

*15. I am surprised the vegetation model does not include the effect of stomatal conductance on evapotranspiration (last paragraph). Please include some detail on the evapotranspiration scheme in the methods.*

The model does calculate evapotranspiration as a function of the stomatal conductance. However, this study is off-line such that we did not account for the $O_3$-driven changes in evapotranspiration and associated meteorological feedbacks because we use prescribed (or observed) meteorology as forcing. We clarified as follows (Page 5, Lines 143-146):

"The model calculates evapotranspiration as a function of the stomatal conductance. However, we do not consider the feedback of the changes in evapotranspiration to the boundary-layer meteorology because we use prescribed meteorological variables from reanalyses in the simulations."

In the last paragraph of the Discussion and Conclusions section, we add:
"The current work has used an off-line approach. Yet, the $O_3$-vegetation-meteorology system is strongly coupled. For instance, plant productivity itself controls the emission of isoprene, a major $O_3$ precursor. The $O_3$-induced modification to stomatal conductance may inhibit evapotranspiration, leading to changes in canopy temperature, precipitation, soil moisture, and other surface hydrology and meteorology (Bernacchi et al., 2007; vanLoocke et al., 2012). In future work, we will study $O_3$ vegetation damage effects using YIBs embedded within a fully coupled global chemistry-climate model framework

in order to account for these feedbacks including altered canopy energy fluxes and partitioning between latent and sensible heat that drive regional climate and hydrology."

*16. Figure 3: Include the PFT type in the title for each figure.*

Added as suggested for both Figs. 1 and 2 (original Figs. 3 and 4).

*17. Figures 7 and 10: While I kind of like the maps with circles of the sites overlying the model results, it is also not possible to see the color of the model at the sites, because the site color overlies the model color, so one is left relying on the surrounding colors. The way around this is to show two separate plots, or perhaps also a difference plot of just the sites.*

We believe the 2D maps in Figs. 5 and 8 (original Figs. 7 and 10) are useful for understanding spatial variability across the U.S. in the model and measurements (we agree it is somewhat qualitative) given the space considerations in a publication. Both plots already include the quantitative scatter plots and regression coefficients for the data represented in the 2D spatial plots. In addition, we have added the separated model and measurement results for Figs. 5 and 8 in the supplemental material (Figures S5 and S6).

**References**


Bernacchi, C. J., Kimball, B. A., Quarles, D. R., Long, S. P., and Ort, D. R.: Decreases in stomatal conductance of soybean under open-air elevation of [CO(2)] are closely coupled with decreases in ecosystem evapotranspiration, Plant Physiol., 143, 134-144, doi:10.1104/Pp.106.089557, 2007.

Bloomer, B. J., Vinnikov, K. Y., and Dickerson, R. R.: Changes in seasonal and diurnal cycles of ozone and temperature in the eastern US, Atmos. Environ., 44, 2543-2551, doi:10.1016/J.Atmosenv.2010.04.031, 2010.

Bonan, G. B., Lawrence, P. J., Oleson, K. W., Levis, S., Jung, M., Reichstein, M., Lawrence, D. M., and Swenson, S. C.: Improving canopy processes in the Community Land Model version 4 (CLM4) using global flux fields empirically inferred from FLUXNET data, J. Geophys. Res., 116, G02014, doi:10.1029/2010jg001593, 2011.

Friend, A. D., and Kiang, N. Y.: Land surface model development for the GISS GCM: Effects of improved canopy physiology on simulated climate, J Climate, 18, 2883-2902, doi:10.1175/Jcli3425.1, 2005.

Ishii, S., Marshall, F. M., and Bell, J. N. B.: Physiological and morphological responses of locally grown Malaysian rice cultivars (Oryza sativa L.) to different ozone concentrations, Water Air Soil Poll., 155, 205-221, doi:10.1023/B:Wate.0000026528.86641.5b, 2004.

Kvalevag, M. M., and Myhre, G.: The effect of carbon-nitrogen coupling on the reduced land carbon sink caused by tropospheric ozone, Geophys Res. Lett., 40, 3227-3231, doi:10.1002/Grl.50572, 2013.

Lombardozzi, D., Levis, S., Bonan, G., and Sparks, J. P.: Predicting photosynthesis and transpiration responses to ozone: decoupling modeled photosynthesis and stomatal conductance, Biogeosciences, 9, 3113-3130, doi:10.5194/bg-9-3113-2012, 2012a.

Lombardozzi, D., Sparks, J. P., Bonan, G., and Levis, S.: Ozone exposure causes a decoupling of conductance and photosynthesis: implications for the Ball-Berry stomatal conductance model, Oecologia, 169, 651-659, doi:10.1007/S00442-011-2242-3, 2012b.

Lombardozzi, D., Sparks, J. P., and Bonan, G.: Integrating O3 influences on terrestrial processes: photosynthetic and stomatal response data available for regional and global modeling, Biogeosciences, 10, 6815-6831, 10.5194/bg-10-6815-2013, 2013.

Oleson, K. W., Lawrence, D. M., Bonan, G. B., Flanne, M. G., Kluzek, E., Lawrence, P. J., Levis, S., Swenson, S. C., and Thornton, P. E.: Technical Description of version 4.0 of the Community Land Model (CLM), National Center for Atmospheric Research, Boulder, CONCAR/TN-478+STR, 2010.

Ollinger, S. V., Aber, J. D., Reich, P. B., and Freuder, R. J.: Interactive effects of nitrogen deposition, tropospheric ozone, elevated CO2 and land use history on the carbon dynamics of northern hardwood forests, Global Change Biol., 8, 545-562, doi:10.1046/J.1365-2486.2002.00482.X, 2002.

Sitch, S., Cox, P. M., Collins, W. J., and Huntingford, C.: Indirect radiative forcing of climate change through ozone effects on the land-carbon sink, Nature, 448, 791-794, doi:10.1038/Nature06059, 2007.

VanLoocke, A., Betzelberger, A. M., Ainsworth, E. A., and Bernacchi, C. J.: Rising ozone concentrations decrease soybean evapotranspiration and water use efficiency whilst increasing canopy temperature, New Phytol., 195, 164-171, doi:10.1111/J.1469-8137.2012.04152.X, 2012.

Zhang, L., Su, B. Y., Xu, H., and Li, Y. G.: Growth and photosynthetic responses of four landscape shrub species to elevated ozone, Photosynthetica, 50, 67-76, doi:10.1007/S11099-012-0004-Z, 2012.