Biogeosciences Discuss., 10, C4556–C4565, 2013
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Biogeosciences Discussions
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Interactive comment on "Integrating O_3 influences on terrestrial processes: photosynthetic and stomatal response data available for regional and global modeling" *by* D. Lombardozzi et al.

D. Lombardozzi et al.

dll29@cornell.edu

Received and published: 27 August 2013

Response to Reviewers:

Thanks to the reviewers for the positive and constructive comments on this manuscript. We have addressed the comments within the manuscript and include our responses to the comments below.

Anonymous Referee #1

The article by Lombardozzi et al. provides a comprehensive meta-analysis of data from existing literature to determine the effect of ozone on photosynthesis and stomatal con-

ductance as a function of Cumulative Uptake of Ozone (CUO). There is a huge need for such an analysis to make sense of all the individual ozone studies that have been published, and to put past synthesizing studies (like the original Reich work from 1987) into proper context. This article should be published, with just some minor revisions as specified here.

The end result is that while ozone negatively affects photosynthesis and stomatal conductance, and photosynthesis more than stomatal conductance, there are not really any significant correlations between the two when analyzed over a large range of experiments. In the discussion the authors do point out the potential role of threshold measures for models, which they are not able to discern from the existing literature. I would like a little more comment in the discussion about models that apply negative ozone effects at the monthly or seasonal time increment, which in some way gets at the idea of applying the overall mean reductions rather than trying to correlate with hourly CUO. These models generally use a threshold index like AOT40, but then apply the results monthly or seasonally based on seasonal regressions against these threshold indices. Is there any possible way there could be significant correlations at this time scale against these types of indices for broad ranges of PFTs even if not at the hourly time scale for CUO? Or, how would the authors suggest applying mean changes instead of correlations?

Author Response: Yes, there is a possibility that there could be a significant linear decrease in photosynthesis and/or conductance at monthly timescales. However, we would not expect this negative decrease to necessarily be correlated with CUO due to the fact that the range of CUO would be quite large even within an individual species over that timescale. Our analysis with [O3] in Figure 5 additionally demonstrates that there is also not a clear pattern of decrease with [O3], so it is not clear that binning the data will improve the relationships of decrease through time. To apply mean changes instead of correlations, we suggest that models decrease photosynthesis and stomatal conductance by a certain percentage (based on specific plant functional type re-

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sponses) at every model time step when plants are chronically exposed to O3. We were not able to incorporate any [O3] or CUO threshold in these analyses, but models can also develop the use of a threshold if that improves predictions of photosynthesis and/or conductance compared to observations. This information is now included the manuscript.

The figures are good but just need some clarification. In the captions it states that p values are listed only when significant, but they seem to be listed on most figures, whether or not the value is greater than 0.05, so I would just remove that statement from the figure captions.

Author Response: This statement has been removed from all figure captions.

The regression equations are supposed to be listed only when significant, so why are they listed for Figure 3?

Author Response: The figure caption for Figure 3 does not state that regression equations are only listed when significant. We have included the regression equations in this figure to demonstrate the similarity between photosynthesis and Vcmax responses to chronic O3 exposure.

The authors should just go through the figures and make sure they are consistent with what they say they are doing in the figure captions. Is figure 4 meant to be just the high confidence data and not also the data that is charcoal-filtered?

Author Response: Figure 4 contains only responses that are compared to the charcoal-filtered air. The figure caption has been updated accordingly.

In Figure 5 (and similarly for 8d), what explains the increase in stomatal conductance for ozone values greater than 150 ppm (is this the guava points)? Is there something peculiar about that experiment that resulted in ozone leading to better plant growth (or what can lead to such an effect)?

Author Response: The data points in the >150 ppb category in Figure 5 are not from

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one particular study. Similarly, the data points in Figure 8d are not from a single study, and all the points that increase compared to control fall into an [O3] category of less than 150 ppb. The positive responses of stomatal conductance in these studies are often attributed to damage to mechanisms that regulate stomatal closure. This point is now more clearly highlighted in the discussion of Figure 8d.

In Figure 9 I assume the information within the figure refers to all the data points?

Author Response: Yes, the text within the figure refers to all the data points. This is now clarified in the figure caption.

Other specific points: 1. First paragraph, Introduction: Ozone increases with more warming, but what about radiation? Often historical or future warming is associated with more clouds and less incoming solar radiation, so that might counteract the effect of the warming.

Author Response: We have removed the reference to warmer temperatures to minimize confusion. This reference originally came from Jacob & Winner (2009), who state that temperature is the single most important meteorological variable influencing ozone concentrations in polluted regions.

2. P. 6977, first paragraph: Why are hydrological changes underpredicted due to ozone? If the effect of ozone on stomatal conductance is generally overrepresented, wouldn't the effect on hydrological changes be overpredicted? Also, rather than stating "if conductance responds differently than photosynthesis" just state "if conductance responds less than photosynthesis".

Author Response: This sentence has been updated to state that changes in the hydrologic cycle are "incorrectly predicted" rather than "under-predicted". We have also changed the phrasing to "if conductance responds less than photosynthesis", as suggested.

3. Methods, p. 6981, I don't understand why if a stomatal conductance value is

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recorded on days 10 and 20, the value for day 11, for example, would equal the value on day 20, instead of some linear interpolation of the two values. The authors show a strong correlation using their method with other published values, but can they please explain this reasoning better?

Author Response: We chose to not use a linear interpolation of stomatal conductance values because stomatal responses were often not linear through time. When linear interpolation was used between the first and last conductance values of papers reporting more than three stomatal conductance values, the linear interpolation frequently did not predict the intermediate conductance values. Therefore, we chose to use the actual data presented within the manuscript rather than data that was interpolated with the possibility of being incorrect.

4. Results, section 3.1, second paragraph: data “were” not “was”

Author Response: This has been changed.

5. Table 1: The rows in this table are not related to the columns, so it is really just a listing of individual items. As such, I would make it look more like a list, rather than aligning columns.

Author Response: It is true that the rows are not related to the columns in this table. We have attached a version of the table that is re-formatted as a list below. However, we find the re-formatted table less clear because it is more difficult to discern each categorical level while keeping the number of studies and the number of data points associated with the appropriate categorical level. The use of a table with column delineation allows those values to be more easily associated with the categorical levels while still clearly highlighting the categories, so we have not updated the table at this time. Instead, we have added text to the figure legend to highlight that the column delineation is only to show the various levels.

6. p. 6985, last paragraph: “studies using : : :” shouldn’t it be “charcoal-filtered air”?

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Author Response: No, it should be “ambient air”. The sentence is stating that the ambient air responses were removed from analyses. This has been made clearer: “. . .within the dataset that removed both low-confidence data and studies using ambient air, . . .”

Anonymous Referee #2

Overall quality of the discussion paper ("general comments"): This manuscript reports on a data set that fills a critical void in regional and global modeling under global change. The analysis provides the basis for integrating ozone responses into ecosystem models, and points out some key differences between the current modeling methodologies and the evidence from empirical studies. The manuscript is quite well written and for the most part is very clear (see details below) and is therefore appropriate for publication with some minor revisions. I would like to see the authors present a little more discussion on the impacts that using linear responses to CUO has/will effect predictions of global carbon uptake, with a little more emphasis on the potential solutions presented in the final section of the discussion.

Author Response: Including linear responses to O3 potentially causes larger decreases in global carbon uptake in the long term, but can also possibly underestimate the decreases in the short term. We have included this information, and more detailed suggestions for incorporating this information into regional and global models, into the concluding paragraphs of the discussion.

Also I think there should be more concise and emphasized statement of the novelty of this study relative to the work presented by Mills et al., and Wittig et al., as well as a more directly addressing the discrepancies between the previously documented responses of yield, and the new reports on gs and photosynthesis (see specific points below).

Author Response: We have included the following sentence in the introduction to emphasize the novelty of this study compared to previous work: “This study improves

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upon work presented in previous syntheses, which document specific plant type responses to O3 concentrations (Morgan et al., 2003; Wittig et al., 2007; Feng et al., 2008), because it determines the physiological responses to chronic O3 exposure as a function of both O3Âň concentration and time in multiple plant functional types."

Individual scientific questions/issues ("specific comments"):

I would like to see a mention of the effects of ozone on other key biochemical processes such as the regeneration of Rubp. While the pool of data on the effects on Jmax is too small to include the type of analysis conducted here, there is potential that these effects are important, especially at high O3 and when CO2 is non-limiting (Martin et al., 2001; Long & Naidu 2002; Morgan etâAËŸ L'al. 2004; Fiscus, Booker & Burkey 2005; Betzelberger et al., 2012).

Author Response: Yes, reductions in Jmax are an important response to O3 exposure that we neglected to include in our original manuscript. We have updated the discussion to include that the reduction of RuBP regeneration, evident in Jmax, is a physiological parameter affected by O3 exposure.

There are also ecosystem-scale responses of water dynamics to O3 documented in Bernacchi et al., 2011 and VanLoocke et al., 2012, that would be appropriate to mention here.

Author Response: Both of these studies are now mentioned in the introduction, highlighting that some studies find decreases in canopy-scale evapotranspiration.

Is it not confounding to correlate gs with CUO given gs is used in the calculation of CUO?

Author Response: Calculations of CUO are not independent from the effects of O3 on stomatal conductance. However, this is the best metric to date for quantifying physiological responses through time. We have included both photosynthesis and stomatal conductance as a function of [O3] (Figure 5) to remove any bias caused by the related-

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ness with CUO, though results of analysis using O3 concentration are similar to using CUO.

In my opinion, the impacts of omitting the open air studies from the analysis should be discussed. As indicated by Wittig et al., 2007, there is evidence that 03 have a stronger effect in open air experiments relative to chamber experiments. I understand the rational for separating them from the studies with CF as a control; however I think it is critical to incorporate these data, as they are likely the most representative data for parameterizing regional models.

Author Response: Data comparing plant responses to ambient air have been incorporated in the Supplemental Information, and the tables including these data are referenced in the methods section. The open-air comparison datasets will therefore be available to readers so that they may also be used for modeling studies. Within the manuscript, open-air studies are included in the overall dataset, and are only removed in the data subsets.

In my opinion the importance of CUO on phenology is under explored here (e.g. Betzelberger et al., 2012). If many studies report significant decreases in yield with increasing O3 exposure (Mills et al., 2007), but the data analysis here shows no such correlation of photosynthesis, than some other factor (e.g. phenology, LAI) must explain this discrepancy. Please expand on this point.

Author Response: Yes, phenological changes might also help to explain the lack of correlation between photosynthesis and CUO. We have included this point in the discussion section and referenced the change in LAI found by Betzelberger et al. (2012) to highlight this point.

Compact listing of purely technical corrections at the very end ("technical corrections": typing errors, etc.).

P6977 L2-5. The sentence on conductance and with links to hydrology is potentially

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ambiguous/confusing. Please clarify with a more explicit statement.

Author Response: These sentences have been updated to be more specific.

I suggest that conductance is explicitly referred to as “stomatal conductance” throughout the manuscript to avoid any confusion with other conductances.

Author Response: Conductance is now referred to as “stomatal conductance” throughout the manuscript.

P 6990 L25. It is unclear what is meant by “stomatal responses in crops become damaged with chronic 03 exposure: : :”

Author Response: This sentence has been updated to read: “. . . the mechanisms regulating stomatal closure in crops become damaged. . .”

P6976 L25. This is not always the case some crops show decreasing gs with greater O3 exposure (Betzelberger et al., 2012).

Author Response: We have added the text: “Some studies report that evapotranspiration decreases with O3 exposure (VanLoocke et al. 2012), though. . .” to clarify that not all studies find increases in transpiration rates.

Table 1. Categories and levels describing the data collected from experiments studying O3 effects on photosynthesis and stomatal conductance. All tree categories are temperate unless otherwise noted. Numbers in parentheses are the number of studies and the number of data points within the associated categorical level: (# of studies, n).

Plant Type: crop (36, 241), deciduous shrub (2, 14), evergreen shrub (2, 9), C3 & C4 grasses (2, 9), herbaceous (4, 50), deciduous tree (59, 646), evergreen tree (24, 183), tropical tree (4, 17)

Plant Age (years): < 1 (57, 443), 1 to 5 (60, 662), > 5 (13, 55)

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Control Air: ambient (35, 349), charcoal filtered (91, 812)

Data Confidence: low (66, 461), medium (49, 582), high (12, 126)

Vulnerability: low (72, 293), medium-low (59, 292), medium-high (51, 292), high (33, 292)

Interactive comment on Biogeosciences Discuss., 10, 6973, 2013.