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Interactive comment on "Competing effects of nitrogen deposition and ozone exposure on Northern hemispheric terrestrial carbon uptake and storage, 1850–2099" *by* Martina Franz and Sönke Zaehle

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Answers to Anonymous Referee #2

Abstract:

Q: What is the effect of N deposition on vegetation growth found in this study? The effect of N-deposition is a key part of the study, so it would be good to reflect that here rather than just focusing on the ozone impact.

A: Abstract extended to take up more results regarding N deposition effects:

'Our simulations suggest that the stimulating effect of nitrogen deposition on regional mean GPP is lower in magnitude compared to the detrimental effect of O_3 during most of the simulation period for both RCPs. In the second half of the 21st century nitrogen deposition dominates the combined effect. The increasing effect of nitrogen deposition on vegetation-C is lower compared to the decreasing effect of O_3 for the entire simulation period. '

Methods:

Q: Line 69: "Evaluated against biomass damage relationships observed in a range of fumigation/filtration experiments with European tree species (Büker et al., 2015; Franz et al., 2018)." And, Line 75: "The tunV C injury functions were calibrated to reproduce observed biomass damage relationships of 75 experiments with a range of European tree species in fumigation/filtration experiments (Franz et al., 2018)." - The biomass damage relationships are mentioned a lot, it would be good to give some more detail here. Which biomass damage relationships are used for calibration and which for evaluation? Need to make explicit to ensure model has not been evaluated against the same data used for calibration.

A: As described in Franz et al. 2018 different versions of the OCN model were created where each version contained a previously published damage function. These damage functions were published by Wittig et al. 2007, Lomardozzi et al. 2012 and Lombardozzi et al. 2013. For the evaluation an independent dataset of damage to European tree species was applied (see Büker et al. 2015). No previously published damage function was able to reproduce the observed biomass data published by Büker et al. 2015. Following this we calibrated a biomass damage function to match the biomass damage data published by Büker et al. 2015.

In line 69 it is stated which biomass data are applied for the evaluation. As described above the damage function applied here is based on the data published by Büker et al. 2015. To clarify this Büker et al. 2015 was added as a reference in lines 74–75: 'The tunVC injury functions were calibrated to reproduce observed biomass damage relationships of experiments with a range of European tree species in fumigation/filtration experiments (Franz et al., 2018, Büker et al. 2015).'

Q: A bit more detail in general would be good. For example, functions are available for high and low ozone sensitivity, different functions have been derived for vegetation in Mediterranean regions (Büker et al. (2015)), and what about functions for grasslands? Some discussion around which functions are used and how that choice affects the results is needed as this is what the results are based on.

A: The OCN model simulates 12 PFTs. Plant groups for Mediterranean regions do not match PFTs simulated in OCN. Büker et al. 2015 grouped Quercus ilex and Pinus halepensis in one group. This is a broadleaf tree species and a needle leaf tree species. In OCN PFTs are either broadleaf or needleaf species. We would have liked to also include damage functions for grass species however there are no suitable dose-response-relationships available. Added in the discussion: 'Due to the lack of suitable damage functions for grass species we here applied the damage functions

developed to match damage to trees. This induces a bias in the damage estimates and will likely results in an underestimation of simulated damage for example for the crop plant functional types.'

Q: Line 76: "Contrary to Franz et al. (2018), the ozone deposition scheme described in Franz et al. (2017) is applied in the simulations here (D-model version in Franz et al. (2017))." - Why? What's the advantage of one over the other, and what is the significance of the D-model version? A bit more explanation and clarification would be good.

A: The difference in the model versions refers to the use of the ozone deposition scheme in the simulations (turned on/ off). The simulated fumigation experiments in Franz et al. 2018 were forced with O_3 concentrations reported from the respective experiments. These O_3 concentrations are already at canopy height and not like our forcing data O_3 concentrations in about 45 m height. Thus the O_3 deposition scheme was turned off in these previous simulations. Here we apply modelled O_3 concentrations with the lowest level in about 45 m height and thus use the model version where the ozone deposition scheme is turned on.

lines 76–77 changed to: 'The O-CN model includes an O_3 deposition scheme that explicitly accounts for the O_3 transport and deposition from the free atmosphere into the stomates (Franz et al. 2017). Here, we use the ozone deposition scheme referred to as D-model in Franz et al. (2017), contrary to Franz et al. (2018) where the O_3 deposition scheme was turned off'

Q: Line 80: What are the PFTs?

A: OCN simulates the following 12 PFTS: tropical broadleaved evergreen, tropical broadleaved rain green, temperate needleleaved evergreen, temperate broadleaved evergreen, temperate broadleaved summergreen, boreal needleleaved evergreen, boreal broadleaved summergreen, boreal needleleaved summergreen, C3 herbaceous, C4 herbaceous, C3 crops, C4 crops. Not all PFTs are present in our simulations here due to the simulated region. They are described in Zaehle and Friend, 2010. A reference to Zaehle and Friend, 2010 is already present in the respective sentence in line 79.

Q: Line 145: more information on the model forcing is needed. What temporal and spatial resolution?

A: The spatial resolution is stated in section 2.4 line 155: 'The model is run at a spatial resolution of 1° x 1°.'

The sentence in line 155 was extended to: 'The model is run at a spatial resolution of 1° x 1° and operates on a half hourly time step.'

Q: Is there a diurnal cycle to the ozone forcing, for example, or is it a daily/monthly mean? What impact might this have on results?

A: The O_3 forcing applied here are monthly mean values. Sentence in lines 147-148 extend to:

'Reduced and oxidised nitrogen deposition in wet and dry form and monthly mean near surface O_3 concentrations are provided by CAM, the community atmosphere model (Lamarque et al., 2010; Cionni et al., 2011).'

The impact of applying monthly mean values compared to hourly values are yet uncertain as stated in line 477-478: 'However, to which extend the omission of a diurnal cycle impacts ozone uptake, accumulation and damage estimates is yet uncertain.'

Q: How was the ozone and nitrogen forcing produced? How does it compare to obser-

vations? Limitations introduced by the choice of forcing data should be considered and discussed at some point in the manuscript? For example, are the ozone and nitrogen forcing uncoupled from the meteorology and CO2 forcing, what are the implications of this?

A: The O_3 and nitrogen forcing was produced by the CAM, the community atmosphere model as stated in line 147-148. For more info on the forcing see Lamarque et al., 2010; Cionni et al., 2011. This is an offline simulation, there will always be inconsistencies between the atmospheric forcing and the land fluxes, this is unavoidable, but it does not invalidate the sensitivity of the land carbon cycle simulation to this forcing. Taken up in discussion:

'The simulations conducted here are run offline and following this atmosphere and biosphere do not feedback on one another. Forcing variables like O_3 concentrations and nitrogen deposition are provided by a different model than the climate. This imposes an inconsistency between the climate and the abundance of the air pollutants whose formation depends on climate variables. Running simulations offline induces unavoidable inconsistencies between the atmospheric forcing and the land fluxes, but it does not invalidate the sensitivity of the land carbon cycle simulation to the forcing.'

Q: Is the land cover fixed and is the LAI prescribed or does the model evolve its own land cover and LAI? What does this look like (LAI and land cover), is the model giving a sensible LAI?

A: The land cover is fixed to values of the year 2000 as stated in line: 148–149. The LAI develops based on abiotic factors like nutrient availability and physical limits like maximum height of water transport within a tree. We evaluated LAI values simulated by O-CN to measured values at FLUXNET sites in a previous paper (see Franz et al. 2017).

Results:

Q: Fig. 1 – I'm finding it hard to see the dotted line.

A: Increased line width.

Q: Fig. 2 – the lines are difficult to see - the colour is too light. I can only see one line in each plot, but the captions says results are shown for RCP2.6 and RCP8.5?

A: Switched to dark blue and increased line width.

Q: Fig. 8 – The colour scale could be improved for these absolute difference plots as it's hard to see clearly what's going on, for example around -50 0 50 for GPP with ozone damage it's hard to see what's increasing or decreasing and where there's no effect. (I'm starting to wonder whether the above might be down to my poor computer screen resolution!)

A: Color scale changed.

Q: Can Table 4 and 5 be combined for easier comparison of the effects of N deposition and 03 damage on GPP?

A: Done.

Q: Can current day estimates of GPP simulated by the model with the effects of O_3 damage and N deposition be compared to observations or other GPP products such as FluxCom or MODIS to give some evaluation of model performance? A check that under current day climate the model behaves sensibly would increase confidence in the results.

A: We evaluated OCN simulated GPP against MTE see Franz et al. 2017.

Discussion:

Q: Section 4.1: What about N-deposition? How does the impact of N-dep on GPP and biomass simulated in this study compare with other studies?

A: Taken up a paragraph in the discussion to address this.

Q: Line 374: What causes the regional hotspots of ozone damage? Is it due to hotspots of high ozone burden, or vegetation type or other environmental causes such as water availability?

A: The cause for simulated O_3 damage hotspots differs depending on the region. As stated in line 280: 'The highest ozone induced absolute reductions in GPP occur in Europe, Eastern US and Eastern Asia where the respective increase in CUO1 is highest.'

The high accumulation values of O_3 (CUO1) can be caused by high O_3 concentrations and/ or traits of the vegetation type. For example regions of peak increases in CUO1 compared to pre-industrial values coincide with regions of a high cover fraction of the boreal needleleaf evergreen PFT (in Canada, the northern US and northern Eurasia) and the temperate broadleaved summer-green as well as the temperate needleleaf evergreen PFT (in Europe, eastern Asia, eastern and western US). Evergreen species keep their leaves for multiple years and hence accumulate damage over a long time. Broadleaf plant functional types are parametrised with a steper damage function and are subject to more damage per unit accumulate O_3 compared to needleaf plant types.

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