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Interactive comment on "Development and evaluation of an ozone deposition scheme for coupling to a terrestrial biosphere model" *by* Martina Franz et al.

Anonymous Referee #2

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The authors present the development and application of a new scheme for estimating stomatal and non-stomatal deposition of ozone within a coupled carbon-nitrogen cycle model. the performance of the model is evaluated against gross primary productivity and latent heat fluxes measurements and estimates of canopy conductances at 26 FLUXNET sites covering a broad range of geographical regions and ecosystem types. The model is found to perform well and simulations are performed to assess cumulative ozone uptake and the resulting reduction in GPP and transpiration at 3 sites (one broadleaf, one needleleaf and one C3 grassland site). They are able to show a clear difference between estimates of ozone uptake and damage made using this scheme and those in which damage is assessed using concentration-based analyses. Overall

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this is a well-planned and well-executed study that is both timely and highly topical, addressing an issue of real concern to society. I strongly recommend publication in Biogeosciences once the following comments have been addressed:

Overall, I find that the manuscript is too detailed and too verbose, with the authors often repeating a point several times, and would benefit from some substantial restructuring. In particular I would recommend that the authors combine Sections 3 and 4 into a single "Results and discussion" section as much of the discussion in Section 4 is merely a repetition of issues raised in Section 3 and in many places reads more like a conclusion. In this case, the conclusion could be made longer. In addition, many of the results presented and discussed in Section 3 are a distraction to the main message (the improvement in estimates of ozone damage when using this new deposition scheme) and would be better moved to Supplementary Information. Specific comments and suggestions follow.

The authors use "ozone" and "O3" fairly randomly throughout the manuscript. I would suggest sticking with one or the other.

Abstract P1, L6 - This is the first use of the acronym OCN - please explain what it is. P1, L12 - "update" should read "uptake" P1, L15-6 - Please re-word, this is hard to follow. I think that you are saying: "When applied at the European scale, we find that including our new ozone deposition scheme substantially affects simulated ozone. . .."

Introduction P2, L22 - replace "consequence" with "result" P2, L24 - replace "extend" with "extent" P2, L27-29 - I suggest making the point here that AOT40 is currently used for regulatory assessment purposes in Europe. P2, L32-33 - Please could the authors explain what they mean by "regional provenances". Do they mean that the same species in different geographical locations differ? Or that different regions have different ecosystems? P3, L8 - Up until this point the authors have referred to AOTX. As AOT40 is the regulatory metric and one that they use in subsequent analysis and discussion I suggest they clearly define AOT40 at this point. P3, L23 - I suggest the

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authors make the point that the threshold values are species-specfic to account for plant sensitivity/tolerance to ozone.

Methods P4, L20 - The model acronym EMEP MSC-W should be defined here rather than at the end of the paragraph, e.g. “The ozone and N-deposition data used for this study are provided by the EMEP MSC-W (European Monitoring and Evaluation Programme Meteorological Synthesising Centre - West) chemical transport model (CTM; Simpson et al., 2012a).” P4, L22 - insert “been” between “have” and “documented” P5, L1 - replace “in” with “at” and remove “height” P5, L7 - replace “in” with “at” and remove “height” P5, L15-6 - replace “leafs internal” with “internal leaf” P5, L16 - parentheses should only be around “2005” P5, L17 - replace “ozone to water vapour” with “ozone from water vapour” P5, L19 - is this factor of 0.7 included in Zaehle and Friend or is this new for this current study? P6, L11 - please explain more clearly what is meant by a low temperature correction factor and why it is needed. P6, L11 - suggest rewording to: “is scaled by a low temperature correction factor, FT, such that” P6, L13 - suggest rewording to: “where TS is the 2m air temperature (C; Simpson et al., 2012a, eq. 60) and 1<FT<2.” P6, L20 - replace “Like” with “As” P7, L1 - parentheses should only be around “2003” P7, L4 - suggest combining to give: “0.5, to prevent negative values in the first fraction of eq. 10”. P8, L4 - Why PODI? My understanding of PODY is that the Y stands for the threshold value not the canopy level. P8, L13 - What is the physical (real-world) interpretation of the parameters 0.22 and 6.16 in eq. 16? P8, L13-4 - Why not just divide by 100 in the equation itself? P8, L17 - Please explain to the general audience why a reduction in An results in reductions in Gst and (particularly) Ci. It is not intuitive why this would reduce internal concentrations. P8, L23 - parentheses should only be around “2010” P9, L2-3 and throughout - I would suggest that the authors re-define or at least use a word description each time these parameters are re-introduced at the start of a new section; else provide a table listing the key parameters for the reader to refer back to. P9, L11 - Are the “summer months” defined here the same as what is then referred to as the “growing season”; if so, please make clear, if not, please define growing season separately. P9, L21 - Please explain what is

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meant by “site levels”. Is this “site-specific” i.e. OCN is run as a column model rather than a 3-D regional model? P9, L22 - square parentheses are not required around CO2 as the text includes the word “concentrations”. P9, L23 - parentheses should only be around “2015”. P9, L23 - rearrange this to read: “Reduced and oxidised nitrogen deposition in wet and dry forms and hourly . . .” P9, L27 - O3 should be subscript P9, L28-9 - Why not use GCM output or reanalyses data where there is a lack of observation data? P9, L30 - what do the authors mean by time-varying here? Surely the progressive simulations also used data that varied with time. Do the authors mean that here it is observations from the site in question for the years in question? P10, L2 - Why have the authors chosen to base LAI on single point, time-specific observations rather than e.g. MODIS LAI data? It seems that this introduces a considerable source of uncertainty. P10, L5 - parentheses should only be around “2015” P10, L6-7 - suggest rewording to read: “. . .are filtered prior to deriving average growing-season fluxes to reduce the effect of model biases on the model-data comparison. Night-time and . . .” P10, L9 - please explain what a “modelled soil moisture constraint factor” is, and why a threshold of 0.8 has been chosen as a filter. Is this based on observations suggesting severe drought impacts alter fundamental plant functioning? P10, L10-1 - suggest rewording to “Daily mean values are calculated from the remaining time steps only where both modelled. . .” P10, L14 - why only use July here when the rest of the analysis is conducted for JJA? P10, L14-15 - why not use the same light level to define daylight as you used to filter the data previously? P10, L16 - suggest rewording to “..FR and for both modelled and FLUXNET-observed GPP. . .” P10, L22-3 - suggest rewording to “. . .1999). Reduced and oxidised nitrogen deposition in wet and dry forms and ozone. . .” P10, L25 - parentheses should only be around “2014b” P10, L25 - insert “and are” before”scaled back” P10, L27 - parentheses should only be around “2011” P10, L28 - square parentheses are not needed around CO2. P10, L28 - parentheses should only be around “2015” P10, L29-30 - Please check dates. If 1961-1970 is used as a spin-up shouldn’t the simulation then start at either 1961 (repeating the first 10 years) or from 1971? P10, L32 - Please explain what an MTE product is. P11, L2 -

replace “Different” by “In contrast” P11, L3 - O3 should be subscript P11, L3-4 - Please explain for the non-specialist audience why the resistances result in a lower canopy concentration.

Results P11, L11 - what do the authors mean that they agree “within the standard deviations”? Are they stating that the data overlap? It would be better to demonstrate this goodness of fit with robust statistical analysis. P11, L13 - should read “. . .very close, with only slight under-“ P12, L3 - remove extra “)” after 10 a P12, L5-6 - please give an example of site management that might result in such variability P12, L8 - why should LE be overestimated and GPP underestimated by OCN at broadleaved forest sites? P12, L13 - what do the authors mean by “vary more widely”? Do they mean that there is a greater difference between modelled and measured values or that there is greater variability in the differences? P12, L14 - Do the means still lie within one standard deviation or not? Is there a tendency for the model to consistently under- or over-estimate? P12, L15-22 - move to SI P12, L23 - general comment regarding section 3.2: Do the reported “biases” in the diurnal cycles reflect those of the means? i.e. is GPP underestimated at the broadleaf site. P12, L24 - diurnal profiles of which variables? State here P12, L32 - remove unnecessary parentheses after m and n. P12, L32 - should read: “with particularly good agreement. . .” P12, L32 - surely it’s more relevant that it is an evergreen needle-leaf forest that it is Finnish? P12, L34 - again, state the type of landcover at this site P13, L1 - Again please explain what is meant by the means being within the standard deviation. P13, L2 - The maximum variability at CH-Oe1 seems to occur during the middle of the day P13, L3 - “whereas” is all one word P13, L4 - what about the peak GC at the CH-Oe1 site? Is it also overestimated by the model? P13, L5 - “simulate” rather than “simulated” P13, L5-6 - is this not a serious short-coming of the model water response parameterisation? I thought the midday depression in GC was a well observed response to water stress. Please comment on the likely implications for your results and conclusions? P13, L7-> Please either change the order of the panels in Figure 2 or the order of the text so that you are presenting the results of the panels in the order in which they appear. P13, L9-

15 - How is RC measured? or is it back-calculated from observed ET and LE? Please comment on the reliability of the observations. P13, L9-15 - what are the implications of the model deviations from observations? P13, L15 - should read "...observed which is slightly lower..." P13, L16 - the minimum velocities appear to be lower than this value for crops P13, L18 - "barely" should read "barley" P13, L16-20 - The modelled velocities at your crop site are well below these. P13, L20 - please rephrase to "The estimates for Hyytiälä also agree..." P13, L16-23 - It would be helpful if you compared the data site by site as before P13, L23 - Why is Vg so noisy for IT-Ro1? P13, L24 - Perhaps it is worth making the point that Vg is not zero because of non-stomatal deposition. P13, L27-28 - Why is there such large variability in the afternoon at IT-Ro1? Is that another sign of water stress? P12-13 - general comments: For Rc, Vg, FR, FStC: what are typical/expected profiles of these variables? Do we really only have observations at 1 or 2 times per day with which to assess model skill? How do these output data compare with estimates from other models? I would strongly recommend that much of the content here is moved to SI and/or presented in a table, with this section only highlighting a few key or interesting features. P14, L2 - add a reminder in the parentheses that GCO3=GC/1.51 P14, L3 - Is this ratio essentially the proportion of deposition that is stomatal? P14, L3-9 - Why have the authors chosen to report the 24-hour average for this variable and not for the others? Section 3.3 This section and the accompanying figure should be moved to SI, with only a few key headline findings included in the main text. P14, L12 - replace "constraint" with "constrained" P14, L13 - "boreal" would be a more useful descriptor than "Finnish" P14, L13 - replace "except of" with "except for" P14, L14 - replace "describing" with "which describes" P14, L17 - replace "compared" with "relative" P14, L22 - insert "canopy conductance" before "GC" P14, L23 - replace "what causes" with "resulting in" P14, L24 - replace "compared" with "relative" P14, L25 - remove "changed values for" P14, L26 - explain the units (%/%) P14, L27 - remove "very" and "varying" P15, L1-2 - has this phenomena (the effect of needle-shedding on CUO) been evaluated? P15, L6-7- what percentage is 250 gC/m2/yr? P15, L8 - remove "to this acceptable agreement" P15, L9 Again what

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percentage is 400 to 900 gC/m2/yr? P15, L12-3 - It also makes it difficult to assess the reliability of the model! P15, L16 - Please explain how N limitation can lead to overestimation of GPP P15, L20 - Fig. 6d does not show GPP. Should this read Fig. 5a? P15, L23-4 - Is it not to be expected that AOT40 closely follows absolute ozone concentrations? P15, L26 - replace "averaged" with "ranged from 60 to 120" P15, L27 - move "(Fig 7 a)" to between "Europe" and "and" P15, L28 - "larger" should read "large" P15, L28 - does this refer to Fig. 7b? P15, L29 - suggest rewording: "with high cover of C4 PFTs, e.g. Black Sea area (see Appendix 12 a,b)." P15, L30-1 - suggest rewording: "...where productivity is low and stomatal O3 uptake reduced by low O3 concentrations or drought control on stomatal fluxes respectively." P15, L31-2 - suggest removing the sentence beginning: "Slight increases or strong decreases..." P15, L32 - "increases" should read "increase" P16, L3 - replace "by" with "of" P16, L4 - insert "Fig. " before "7 c" P16, L4 - insert "of transpiration" after "3-4%" P16, L4 - remove "to" before "4-6%" P16, L5 - insert "relative" before "reductions" P16, L7 - should read "Black Sea" P16, L8 - insert "Fig." before "7 d" and replace "They are" with "These are" P16, L10 - please explain why a reduction in transpiration matters. P16, L15 - suggest rewording: "...CUO1.6 increases more strongly by 35%..." P16, L18-9 - It seems to me that in this study simulation D is effectively the base case and D-STO and ATM are sensitivity tests. It would therefore make more sense to swap panels a and c in Figure 9. Furthermore, it seems to me that this is the real headline message of this study - that the ozone deposition scheme substantially alters estimates of impacts. this needs far more emphasis (it is currently hidden by the wealth of detail in the rest of this discussion) and Figure 9 should include further panels showing how CUO changes (see below).

Discussion This section seems redundant. Much of it is either already stated in the Results section or could be moved to form part of a more robust conclusion. P16, L24-5 - replace "with the aim" with "in order to" P16, L25 - replace "effect to net" to "effect on net" P16, L25 - remove "the" before "regional" P16, L28 - replace "assuming" with "the assumption" P16, L28 - replace "would be identical" with "is identical" P16, L29

- replace “in 45m” with “at 45m” P16, L30-1 - suggest rewording: “. . .and deposition variables i.e. calculated ozone uptake . . .” P16, L32 - P17, L2 - suggest rewriting: “Our sensitivity analysis does show that a correct estimate of canopy conductance is crucial for calculating plant ozone uptake. We find that the model produces reasonable estimates . . .” P17, L2 - replace “a range of” with “some” P17, L7-8 - suggest rewriting: “Reliable estimates of surface ozone concentrations are also essential for calculating canopy ozone uptake FstC” P17, L8-9 - suggest rewriting: “. . .airspace due to biogenic volatile organic compounds (BVOCS) emitted by vegetation is (at least partly) implicitly included in the” P17, L9-10 - Does this mean there is a degree of double accounting? P17, L11 - suggest “performance” or “efficacy” in place of “functionality” P17, L15 - suggest combining these to form a single sentence: “. . .changes in GC emphasising the importance. . .” P17, L15-16 - How can reliable estimates be obtained? P17, L18 - replace ”indicates”with “indicate” P17, L26 - replace “impose” with “introduce” P17, L29 - replace “suitable” with “well able” P17, L30 - remove first occurrence of “finding” and replace “encourages” with “supports” P18, L2 - reword: “Estimates of the regional damage to annual average. . .” P18, L2 - make clear this is transpiration rather than temperature (I assume) P18, L2-3 - remove “the period of the years” P18, L3 - replace “lower” with “low” and “previous” with “previously” P18, L3 - should read ”Meta-analyses” and “an 11%” P18, L6 - should read “Land Model” P18, L7 - reword: “..transpiration have been estimated as 5-20% for Europe and 2.2% globally. . .” P18, L9 - reword: “plant types. Damage was only related to cumulative ozone uptake for one plant type with a very small slope” P18, L9 - please explain the real-world meaning of a small slope. P18, L14 - use “discrepancies” or “differences” rather than “deviations” P18, L14-15 - replace “the usage of very different” with “differences in” and then remove “different”, “differing” and “non-identical” P18, L16 - replace “differences in simulating” with “simulation of” P18, L17 - reword: “The key difference from the previous study is our use of the ozone. . .” P18, L17 - remove “included in our study” P18, L21 - remove “the” before “non-stomatal” P18, L22 - should read “To obtain as accurate as possible an estimate. . .” P18, L23 - replace “it’s” with “their” P18, L24 - replace “considered” with

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"accounted for" P18, L25 - suggest moving "(possibly PFT specific)" to come before "flux threshold" P18, L25 - "it's" should read "its" p18, L25 - should the "Y" in "CUOY" be a subscript? P18, L32 - insert "see" before "LRTAP" P18, L33 - replace "but only" with "there are" and "exists for" with "of" P19, L2-4 - What is the implication of this disadvantage to the findings reported here? P19, L5 - replace "damage estimates" with "relationships" P19, L6 - replace "estimates" with "metrics" P19, L13 - replace "should be regarded too" with "also requires further analysis"

Conclusion This section needs to be substantially expanded. The authors would also do well to identify (even using bullet points if necessary) the key findings of their study and the implications for the land surface and atmosphere research communities. Much of Section 4 could be distilled and included in the Conclusion section.

P19, L20-1 - replace "to generally consider" with "that" P19, L21 - reword: "non-stomatal ozone uptake is routinely included in model assessments of ozone damage . . ." and remove "estimate" after "better" P19, L22 - remove "used" P19, L23 - insert "used here" after "scheme" P19, L23 - reword: "importance of reliable modelling of canopy conductances as well as realistic. . ." P19, L24 - insert "as" before "accurate" P19, L26 - remove "Desirable are" P19, L27 - insert "are also desirable" after "types" P19, L29 - replace "regarded" with "considered" P19, L29 - insert "," after "thresholds"

Appendix A P20, L1 - capitalise "Aerodynamic Resistance" and remove "(Appendix material)" P20, L3 - remove "," after "heights" and replace "This data is" with "These data are" P20, L4 - replace "in 45m height" with "at 45m" P20, L7 - what does U10 mean? If at 10m, why is this an appropriate height at which to calculate u*? P20, L9 - replace "in 45m height" with "at 45m"

Appendix B P20, L21 - Why not use ORCHIDEE to calculate biogenic emissions? P20, L22 - remove "NO from" P20, L24 - Volcanic emissions of what? Which compounds?

References Please check references carefully. Tuovinen et al., 2004a and 2004b are the same paper Tuovinen et al., 2009a and 2009b are the same paper

Figures: Throughout - I would suggest that rainbow scale is not the most effective and that limited colour graduated scales would be easier to interpret.

Fig. 1 Panel (d) - Again, why choose a non-varying measure of LAI (i.e. point samples) rather than MODIS or similar, particularly as you comment on the validity of these measurements for the specific time period modelled? Panel (d) - In its present form this is not a useful panel and I would suggest that it is removed or moved to SI. It distracts from the good fit the model shows to other (more important) variables. Caption - line 4 should read ". . .which are based on point. . ."

Fig. 2 x-axis scale - Hours should have a 4-hour or 6-hour scale, not 5. Please state explicitly whether this is local time or UTC. y-axis scale - As the scale is the same across each row I would suggest only one axis scale is required. y-axis scale - for variables that can be negative please add a dashed horizontal line to indicate 0.0; otherwise the axes should cross at zero.

Fig. 3 scales - please define the scales used in Fig 3 more carefully, either here in the caption or in the appropriate place in the main text.

Fig. 4 This figure should be SI. In addition, it is virtually unreadable. I had to view at 600% zoom to make out the yellow and red lines

Fig. 5 scales - don't use the same colour scales for both absolute values and changes; changes are best shown on blue-red scales. Use e.g. green scale for crop cover.

Fig. 7 scale - please improve the scales; I suggest using a graduated single or limited colour range. panel labels - please use more descriptive panel captions (not just "damage")

Fig. 9 To me, this is the KEY figure in this paper. I suggest that you add panels showing changes in CUO from D to D-STO and ATM respectively (giving a 5 panel plot)

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