Response to Reviewers' Comments on "Influence of plant ecophysiology on ozone dry deposition: Comparing between multiplicative and photosynthesis-based dry deposition schemes and their responses to rising CO_2 level" by Sun et al.

The comments of the referee are given as plain text, while the authors' response is given in *italic.* We have revised the paper based on the reviewers' comments.

Response to Referee #2

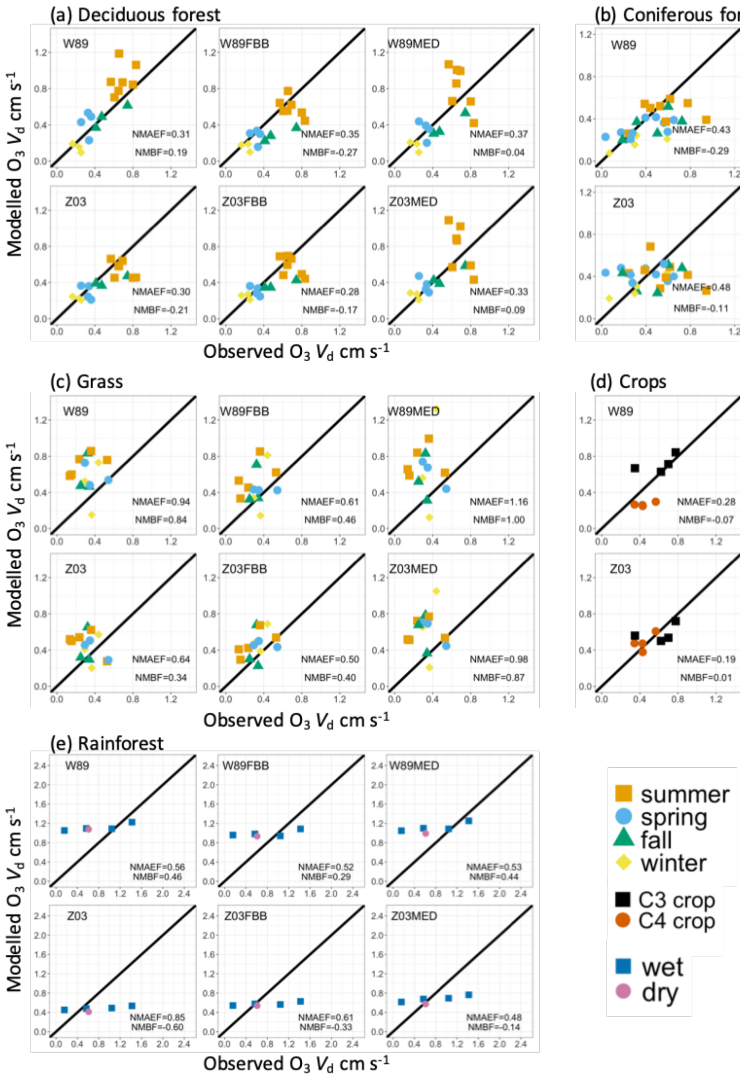
The authors examine the impact of carrying the stomatal conductance parameterization on the predicted deposition velocity. Comparisons are made between the well-used Wesely (1989) and Zhang et al. (2003) approaches as well as derivative parameterizations developed by substituting two different photosynthesis-based approaches into both the Wesely and Zhang approaches. Results are compared against observational data from several flux studies as well as the SynFlux dataset. Overall, the paper is sound but could benefit from additional editing. The text in Table 3 is very small as is the text in Figure 1. I am surprised that the photosynthetic models did not offer greater improvements in modeled values and would be interested in your thoughts on that. I would also be interested in seeing values of the correlation coefficient.

- *We thank the reviewer for the insightful comments and suggestions. The manuscript has been revised accordingly.*
- *We agree that photosynthesis-based stomatal conductance models do not significantly improve model performance. In the paper, we have therefore mentioned this at various places, highlighting that both photosynthesis-based schemes and Z03 multiplicative schemes are better than W89, mostly likely due to their ability to capture plant responses to water stress and VPD, e.g., P15 L442: "... In general, accounting for stomatal response to VPD and/or water stress using multiplicative or photosynthesis-based stomatal algorithms can improve model performance in capturing diurnal variations of G_s and v_d."*
- *The merits of multiplicative methods such as lower computational costs and higher compatibility are undeniable for Earth system modeling. Multiplicative methods parameterized with observations can also be improved whenever more field measurements are available. Yet, with more biophysically meaningful and measurable properties, photosynthesis-based methods are principally more mechanistic than multiplicative stomatal methods, and can better address plant responses to a changing environment (e.g., rising CO_2 and temperature) with rapidly expanding knowledge from biologists. Furthermore, parameters for photosynthesis-based methods can be obtained from leaf-scale measurements, which overall cost less than dry deposition flux measurements that are used for parameterizing multiplicative model. We have now emphasized these points more in the Conclusions and Discussion, e.g., P26 L681: "Our attempt to include the empirical CO_2 response function of Franks et al. (2013) in multiplicative stomatal schemes result in a much larger reduction in global G_s that doubled the average relative change computed with photosynthesis-based stomatal schemes, and potentially overstates stomatal responses to elevated CO_2 under future scenarios."*

We calculated Pearson correlation coefficient R for seasonal average modelled and observed v_d at all observational sites: W89 ($R = 0.61$), W89FBB ($R = 0.56$), W89MED ($R = 0.48$), Z03 ($R = 0.37$), Z03FBB ($R = 0.47$), Z03MED ($R = 0.41$). The p-values for all coefficients here are <0.01.

We updated font size of Table 3 and Figure 1 with colorblind friendly palette as below:

PFT	Season	Observation	W89			W89FBB			W89MED			Z03			Z03FBB			Z03MED		
		mean±sd	mean±sd	NMBF	NMAEF	mean±sd	NMBF	NMAEF	mean±sd	NMBF	NMAEF	mean±sd	NMBF	NMAEF	mean±sd	NMBF	NMAEF	mean±sd	NMBF	NMAEF
DBF	JJA	0.69±0.10	0.90±0.17	0.32	0.32	0.59±0.10	− 0.16	0.26	0.81±0.24	0.18	0.41	0.55±0.09	− 0.25	0.30	0.58±0.11	− 0.18	0.26	0.78±0.25	0.14	0.41
	MAM	0.33±0.02	0.42±0.13	0.27	0.43	0.28±0.08	− 0.21	0.23	0.35±0.10	0.05	0.26	0.29±0.08	− 0.13	0.27	0.31±0.05	− 0.09	0.18	0.37±0.08	0.10	0.21
	SON	0.52±0.20	0.49±0.12	− 0.05	0.18	0.29±0.07	− 0.78	0.78	0.39±0.13	− 0.34	0.34	0.41±0.06	− 0.26	0.26	0.37±0.05	− 0.39	0.39	0.46±0.11	− 0.11	0.13
	DJF	0.25±0.08	0.14±0.05	− 0.86	0.97	0.14±0.05	− 0.86	0.86	0.15±0.06	− 0.72	0.87	0.24±0.04	− 0.04	0.21	0.26±0.03	0.02	0.23	0.26±0.04	0.05	0.27
ENF	JJA	0.58±0.23	0.46±0.12	− 0.29	0.35	0.46±0.11	− 0.30	0.42	0.47±0.10	− 0.27	0.40	0.42±0.14	− 0.39	0.68	0.52±0.14	− 0.14	0.44	0.53±0.13	− 0.12	0.42
	MAM	0.46±0.15	0.35±0.11	− 0.31	0.43	0.34±0.10	− 0.34	0.40	0.37±0.12	− 0.24	0.37	0.42±0.06	− 0.10	0.31	0.43±0.09	− 0.07	0.26	0.46±0.11	− 0.01	0.26
	SON	0.47±0.22	0.35±0.12	− 0.35	0.43	0.28±0.07	− 0.64	0.68	0.26±0.04	− 0.83	0.85	0.39±0.13	− 0.21	0.46	0.41±0.15	− 0.13	0.37	0.40±0.12	− 0.18	0.43
	DJF	0.32±0.21	0.17±0.07	− 0.87	0.89	0.19±0.08	− 0.66	0.73	0.16±0.06	− 0.98	1.01	0.30±0.11	− 0.08	0.29	0.30±0.15	− 0.05	0.28	0.28±0.12	− 0.14	0.36
CRO	/	0.53±0.16	0.50±0.26	− 0.05	0.29	0.72±0.15	0.37	0.43	0.81±0.13	0.54	0.54	0.54±0.11	0.03	0.18	0.61±0.15	0.16	0.32	0.67±0.14	0.27	0.32
TRF	/	0.76±0.48	1.11±0.07	0.46	0.56	0.98±0.06	0.29	0.52	1.10±0.10	0.44	0.53	0.47±0.05	− 0.60	0.85	0.57±0.04	− 0.33	0.61	0.66±0.07	− 0.14	0.48
GRA	JJA	0.33±0.17	0.72±010	1.21	1.21	0.59±0.21	0.82	0.82	0.84±0.28	1.56	1.56	0.50±0.12	0.53	0.79	0.50±0.16	0.51	0.51	0.68±0.21	1.08	1.08
	MAM	0.39±0.13	0.58±0.13	0.48	0.48	0.43±0.00	0.08	0.28	0.62±0.16	0.57	0.74	0.42±0.11	0.06	0.48	0.46±0.03	0.17	0.36	0.62±0.15	0.56	0.72
	SON	0.30±0.06	0.59±0.21	1.00	1.20	0.46±0.22	0.55	0.78	0.55±0.26	0.88	1.03	0.42±0.29	0.43	0.76	0.46±0.20	0.54	0.80	0.54±0.22	0.82	0.95
	DJF	0.33±0.05	0.34±0.26	0.02	0.68	0.24±0.14	− 0.37	0.56	0.34±0.31	0.04	0.77	0.31±0.15	− 0.08	0.46	0.35±0.18	0.06	0.49	0.443±0.32	0.31	0.79



Technical comments:

Line 111: It would be helpful to include examples of the biosphere-atmosphere interactions that are lacking in CTMs

- *Thank you for the suggestion. Revised as follows:*

  "Very few studies have addressed the atmospheric chemistry-vegetation feedbacks due to lack of representation of biosphere-atmosphere interactions in CTMs (Centoni, 2017; Lei et al., 2020). For example, O_3-induced vegetation damage can worsen O_3

air quality by modifying O_3-relevant fluxes (Monks et al., 2015; Sadiq et al., 2017; Zhou et al., 2018), and limit land carbon sink (Sitch et al., 2007; Lombardozzi et al., 2015). Two-way nitrogen exchange that includes the impacts of nitrogen deposition on soil and plant biogeochemistry and the subsequent secondary effects on atmospheric chemistry is also largely lacking (Zhao et al., 2017; Liu et al., 2021). Higher ambient CO_2 concentration can also affect plant stomatal conductance and photosynthesis, in turn causing changes in transpiration and hence in surface temperature, cloud cover, and meteorology (e.g., Sanderson et al., 2007)."

Lines 140-143: There are multiple implementations of the W89 and the Z03 schemes in CTMs. Please be more specific here as to which implementation you used for both frameworks and not any specific differences that would have implications to the results here.

- *Thank you for your suggestion. Revised as suggested:*

  "We examined two major dry deposition modeling frameworks: (1) the Wesely framework, which has been widely used in global atmospheric chemistry models (Hardacre et al., 2015; Morgenstern et al., 2017; Porter et al., 2019; Silva and Heald, 2018), and in this study we used the Wesely scheme version (referred to as W89 hereafter) as currently implemented in the GEOS-Chem chemical transport model with modification by Wang et al. (1998); (2) the Zhang et al. (2003) dry deposition framework used in several regional air quality models (Nopmongcol et al., 2012; Schwede et al., 2011; Zhang et al., 2009). Here we implemented the scheme as described in Zhang et al. (2003) (referred to as Z03 hereafter)."

Line 170: Not specific to this line of text per se, but little is said about the stomatal blocking factor that is in the Z03 scheme and the potential effect of it. While it doesn't affect the actual value of the stomatal resistance, it definitely has implications for the contribution of that pathway to the overall canopy resistance and the deposition velocity. It merits a bit of attention in the paper.

- *Thanks for the suggestion. We conducted tests using Z03 without stomatal blocking for rainforests where the highest precipitation is expected, and Z03 simulates lower v_d during the day with stomatal blocking. Stomatal blocking factor contributes little to the differences in simulated seasonal average v_d rainforest between W89 and Z03. We added discussion about stomatal blocking factor in Z03:*

  "Z03 considers stomatal blocking that occurs after rain or dew events, and thus simulates lower dry deposition velocities at measurement sites with high precipitation. However, for most observational sites used in this study, precipitation rates are lower than the stomatal blocking threshold throughout the measurement periods, and stomatal blocking contributes little to the differences in simulated v_d across different schemes."

Lines 220-226: It has previously been stated that the W89 version is the one in GEOS-Chem and it doesn't need to be restated here. The focus here is clearly on the stomatal parameterization. Have other papers already addressed the non-stomatal resistances? Perhaps cite any studies that have here and maybe make recommendations about whether that work should or could be part of future work.

- *Thank you for your suggestion. Revised as suggested:*

"To evaluate the two dry deposition frameworks and to compare the multiplicative and photosynthesis-based stomatal schemes, we replaced the default stomatal parameterization in W89 and Z03 dry deposition frameworks with FBB and MED, and in total six dry deposition configurations were tested as described in Table 1. The differences between the W89 and Z03 frameworks lie in not only stomatal parameterization, but also non-stomatal deposition structures and algorithms. For non-stomatal resistances, Z03 considers variations from meteorological (e.g., RH, u_*) and biological factors (e.g., LAI, wet or dry canopy), while W89 uses simpler representation of cuticular resistance and aerodynamic resistance (Table 1). Mechanistic non-stomatal parameterization remains challenging due to uncertainties in inferred non-stomatal deposition estimates, such as difficulties in separating non-stomatal uptake from soil uptake and in-canopy chemistry (Clifton et al., 2020a). Future evaluation of non-stomatal algorithms requires further measurements such as BVOC emissions and soil moisture (Clifton et al., 2019)."

Lines 227-228, it would be helpful to add "in TEMIR" after mode for clarity or you could add text to the model description to indicate that it runs both in single-site mode and as a gridded model.

- *Thank you for your suggestion. Revised as suggested.*

Lines 239-240: It would be helpful here to indicate how the model handles multiple land use types within the grid cell. Again, this could be added here or in the model description. It is stated a bit later but would be better addressed in Section 2.1. The grid cell size is pretty large for ecosystem specific studies. What impacts might that have?

- *Thank you for your suggestion. Subgrid heterogeneity such as vegetation traits is poorly represented by large grid cells in general. Simulated v_d and G_s values under extreme local meteorological conditions might also be flattened. These could be better resolved in future studies where models can be run efficiently at finer scales with high-resolution input data.*
- *Revised as suggested: "... For global simulations, the model was run at a spatial resolution of 2°×2.5° driven by MERRA-2 meteorology for each dry deposition configuration. v_d and G_s were summed up by PFT fractions over vegetated land within each grid cell."*

Line 265: It would be helpful to provide the Penman-Monteith method in the Supplemental.

- *Thanks for the suggestion. Added P-M method in the Supplementary.*

  "We use evaporative-resistance form of Penman-Monteith method to keep consistent with SynFlux stomatal conductance. The leaf stomatal conductance is:

  $$g_w^{-1} = \frac{\varepsilon\rho(e_s(T_f)-e)}{pE} - (r_a + r_{b,w}),$$

  where ε is mass ratio between water and dry air, p is air pressure, E is surface moisture flux, T_f is leaf temperature, $e_s(T_f)$ is the saturation vapor pressure at leaf surface. r_a is aerodynamic resistance, $r_{b,w}$ is quasi-laminar layer resistance to water vapor. T_f is estimated as follows:

$$T_f = T + \frac{H(r_a + r_{b,H})}{c_p \rho},$$

where T is air temperature, H is sensitive heat, c_p is specific heat of air, ρ is the mass density of air, $r_{b,H}$ is quasi-laminar layer resistance to heat.

Stomatal conductance of O_3 is calculated with molecular diffusion coefficient ratio 0.6 between O_3 and water vapor:

$g_s = 0.6 g_w$ *"*

Line 292-292: I don't agree with the statement that the schemes can generally capture the magnitude for the major PFTs. The models do not capture the range of values observed for the coniferous forest or the rainforest and predict a range of values for grasses that is larger than the observations.

- *Thanks for the suggestion. Revised as suggested:*

  "~~The six dry deposition schemes can generally capture the magnitude of seasonal daytime v_d for major PFTs~~. The dry deposition schemes used in this study fit observed v_d better for deciduous forest and crops. Yet different schemes cannot reproduce daytime v_d well for coniferous forest, grass and rainforest."

Line 305: How did you determine that the modeled vd for grasses is largely determined by the minimum stomatal resistance?

- *Thanks for your comment. Overestimation of v_d compared in this study is different from previous works where grassland v_d is underestimated. Revised as below:*

  "In previous studies, models mostly underestimated grassland v_d (Hardacre et al., 2015; Pio et al., 2000). Discrepancies between our modeled grassland v_d and previous works mainly arise from the prescribed minimum stomatal resistance (r_{smin}) and LAI."

Line 469: It might be helpful here to add a few sentences comparing these results to the ones for the field study sites.

- *Thanks for the suggestion. Revised as suggested:*

  "…while MED overestimates G_s (NMBF = 0.44), and W89 simulates with NMAEF = 0.41, lower than other schemes (NMAEF > 0.50). Evaluation with long-term measurements in Sect 3.2 finds similar model performance using different stomatal schemes. As shown in Fig. 4a and Fig. 4c, Z03 and FBB simulate comparable diurnal G_s cycles. MED produces higher G_s values than FBB in general."

Line 535-536: It isn't clear to me where in Figure 9a, the non-stomatal vs stomatal deposition rates are provided.

- *Thanks for the comment. It is interpreted from Fig. 10e where Z03 has lower stomatal deposition than W89. Revised as suggested:*

  "Z03 simulates lower daytime v_d than W89 in most regions, except for evergreen needleleaf regions at high latitudes (Fig. 9a), where Z03 simulates higher stomatal

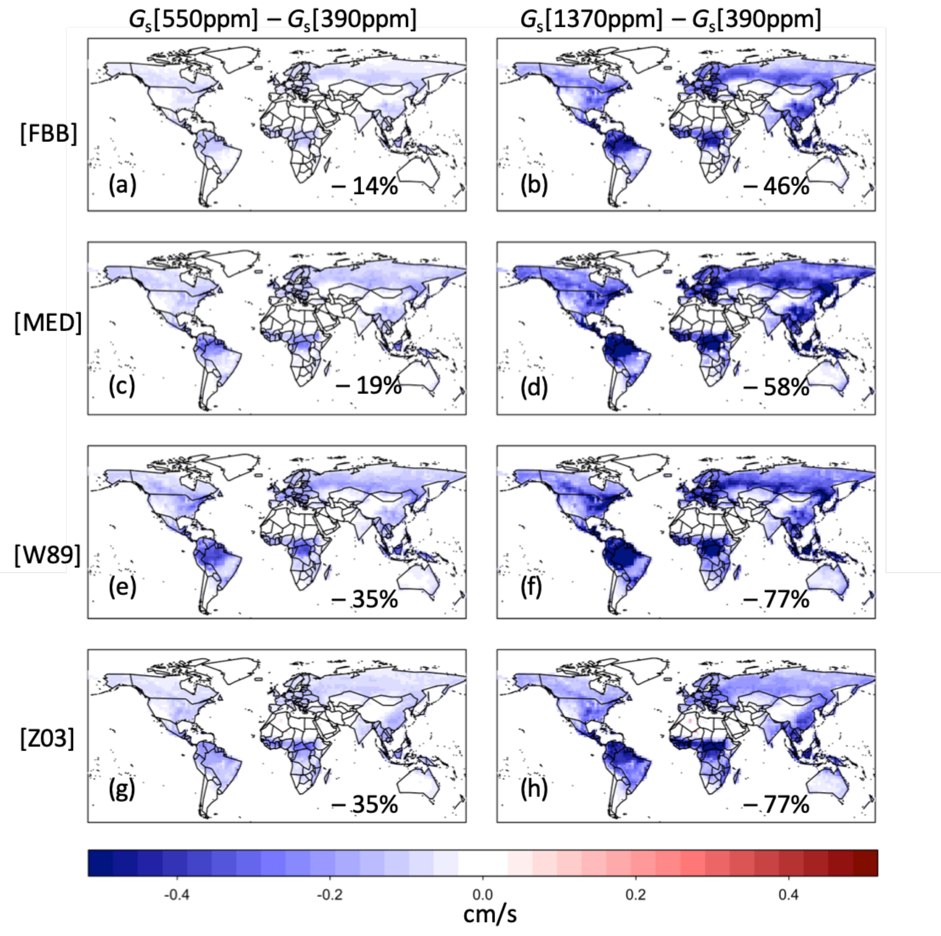
deposition than W89 (Fig. 10e). Hence differences in daytime v_d for these regions are caused by higher non-stomatal deposition simulated by Z03."

Line 385: Define RuBP; also is equation 8 also from Franks et al.?

- *Thanks for the suggestion. Yes, equation 8 is from Franks et al. (2018). We added definition of RuBP as suggested: RuBP (ribulose 1,5-bisphosphate)*

Figure 11: Why is W89 only used in this figure rather than including Z03?

- *Thanks for the suggestion. We assumed W89 and Z03 use the same factor (Eq. 8) to represent the relative change in stomatal conductance under rising CO_2 concentrations and that the simulated changes in stomatal conductance are identical. We added Z03 as suggested.*



Line 622-623: The results are not very convincing for switching to a photosynthesis-based model

- *Thanks for your comments. More caution is now conveyed, as stipulated above.*

Line 637: I am a curious about the use of "guaranteed" here.

- *W89 was parameterized with observations and intended to capture long-term, or seasonal, dry deposition velocities.*

Line 648: While I fundamentally agree that photosynthesis-based models offer opportunities for improving our estimates of air-surface exchange, I think there is still a lot to be considered when coupling in grid models with subgrid variability in vegetation types.

- *Thank you for your comments. More caution is now conveyed and more discussion is devoted to this, as stipulated above.*

Editing notes:

Lines 27 – 29: Sentence could benefit from editing

- *Revised as suggested.*

Line 89: Consider rewording to "tree and crop species of concern"

- *Revised as suggested.*

Line 90: Add "the" before DOSE

- *Revised as suggested.*

Line 127-128: Change "discussed" to "discuss"; add "the" before stomatal; parameterization should be plural

- *Revised as suggested.*

Line 157: add "the" before dry

- *Revised as suggested.*

Line 179: change its to their

- *Revised as suggested.*

Line 194: change "is" to are

- *Revised as suggested.*

Equation 4: the concentration should be denoted by C not c

- *Revised as suggested.*

Line 213: add the before photosynthetic

- *Revised as suggested.*

Line 277: Insert "the" before different and dry

- *Revised as suggested.*

Figure 1: in the caption, add "where" before different. I would also suggest using different colors as the current ones may not be optimal for users with color blindness issues.

- *Thanks for the suggestion. Revised as suggested. Figure plotted with "Okabe-Ito" palette (https://jfly.uni-koeln.de/color/) which is friendly to colorblind people.*

Line 352: add "mean: after monthly

- *Revised as suggested.*

Line 360: delete "in this"

- *Revised as suggested.*

Line 377: Perhaps the second vd in the sentence should be Gs?

- *Yes. Revised as suggested to be precise.*

Line 604: I have seen those experiments referred to as FACE not FREE

- *Thank you. Corrected as suggested.*

References

Clifton, O. E., Fiore, A. M., Munger, J. W., & Wehr, R.: Spatiotemporal controls on observed daytime ozone deposition velocity over Northeastern U.S. forests during summer, J. Geophys. Res.-Atmos, 124, 5612– 5628, https://doi.org/10.1029/2018JD029073, 2019.

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Lombardozzi, D., Levis, S., Bonan, G., Hess, P. G., & Sparks, J. P.: The influence of chronic ozone exposure on global carbon and water cycle, J. Climate, 28(1), 292–305, https://doi.org/10.1175/Jcli-D-14-00223.1, 2015.

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