1 Answer to Reviewer 2

Emmerichs et al. assessed the implementation of various functions related to plant water stress in the ECHAM/MESSy model and examined their subsequent effects on change in evapotranspiration. The authors also investigated the impact of changes in evapotranspiration on ground-level ozone. While this modelling exercise is valuable for pinpointing the appropriate functions implemented in their atmospheric chemistry model, there are a few drawbacks in the current form of this paper, particularly regarding the overall structure and model-data validation. Here I provide some comments for the authors' and editor's consideration.

We are very grateful to Reviewer 2 for the thoughtful and constructive comments helping us improve the quality of the manuscript. We try to consider all the comments. Please find our reply (in blue) to your comments (black, italic) below.

2 Major comments:

The title of this paper is misleading. It led me, as a reader, to expect a primary focus on how plant-water stress influences ground-level ozone. However, two-thirds of the Results are on testing/comparing the impact of changes in plant-water stress functions on plant transpiration, evapotranspiration, and air temperature. Ozone is only a minor aspect of the findings. It might be more appropriate to adjust the title to better reflect the actual results. If the authors aim to quantify the effect of plant water stress on ozone, the results should provide the correlation between the water stress index/ET/Temperature and ozone concentration.

We understand the reviewers opinion and adjust the title to:
'The influence of plant-water stress on vegetation-atmosphere exchanges: implications for ozone modelling. '

2. It is not clear to me from the text how the change in evapotranspiration (ET) will affect ozone concentration through atmospheric chemical processes. I was trying to get some basics from the Introduction and Method but was unsuccessful. Although the author does mention chemical processes in Section 3.5, it would be more effective to introduce this information much earlier to provide a general understanding of how changes in ET could impact ozone. While the relationship may be self-evident in atmospheric chemistry, it is still essential to include basic information in the paper to present a comprehensive story.

We add basics on tropospheric ozone and its dependence on meteorology to the introduction (see answer of 3. item in 'Minor comments'. The description of O3-related chemistry in Section 3.5 was also extended in response to the first reviewer.

3. A major concern regarding the model's performance is the absence of model-measurement validation. All data presented in Section 2.2 consist of simulations from other models. No ground-based data were used to validate the ET estimates obtained by modifying the plant-water stress functions in their model. Data from EMUETSAT or GLEAM may provide a robust estimation of ET by validating their performance against ground-based measurements. As an independent model, the outputs from ECHAM/MESSy should also be validated against ground-based measurements. It is feasible to get the ET measurements from the FLUXNET network nowadays. A direct comparison in a 1:1 space, plotting ground-based measurements against model estimates, would provide a clear assessment of the model's performance and illustrate how changes in plant water stress functions impact ET and other model outputs.

We certainly acknowledge the advances of FLUXNET. However, this global model study can not provide a point-to-point comparison. Although we use relatively high spatial resolution for a chemistry global model, the grid boxes are too large with respect to the footprint region of the ground-based measurements. Spatial heterogeneity of land characteristics is very important for ET and soil moisture at the measurement sites and the global model cannot resolve those scales. To account for the broad spatial coverage of the model results a global observation dataset (TROPOSIF and GLEAM) is better suited. Furthermore, we chose a rather recent study period in line with the focus of our funding project SCENIC. Data from this period, however, is not available for the most sites of FLUXNET.

3 Minor comments:

1. The first 4 sentences of the abstract were written in a way that jumps from one topic to another without logical connections.

'Evapotranspiration is important for Earth's water and energy cycles as it strongly affects air temperature, cloud cover and precipitation. Leaf stomata are the conduit of transpiration. Thus, their opening is sensitive to weather and climate conditions. This feedback can exacerbate heat waves and can play a role in their spatio-temporal propagation.'

to

'Evapotranspiration drives the Earth's water and energy cycles and thus strongly affects air temperature, cloud cover and precipitation. Transpiration through leaf stomata contributes a major fraction. The stomatal opening is sensitive to weather and climate conditions. The weather sensitivity can lead to the amplification of heat waves determining their spatio-temporal propagation.'

2. "Overall, the new functionalities" What do these new functionalities refer to? No mention in the previous text.

Here, we refer to the new implemented functions/parametrisations. We will change the wording to 'new parametrisations'.

3. Before Line 55, there should be a section to introduce the research background on ozone using modelling.

We agree and add a paragraph on tropospheric ozone:

Tropospheric ozone is a major air pollutant harmful to humans and plants. Its spatial and temporal evolution not only depends on emissions but it is also crucially dependent on meteorological variables like temperature. In fact, radical reactions dominating the O_3 formation are enhanced at high temperatures. Also, plant emissions of isoprene, a major ozone precursor, strongly respond to increasing temperature rising exponentially until a temperature of 42°C is reached (Guenther et al., 2006). Higher temperatures as well as dryness inhibit dry deposition, an important sink of ozone and its precursors. A major part of dry deposition happens at the stomata during the water-/CO_2-exchange of plants (transpiration/respiration). As plants close their stomata to limit the water loss (Katul et al., 2009) ozone uptake is strongly reduced.

In line 60, we add:

For assessing the impact of the different plant-water stress on ozone, we use a comprehensive chemistry with 310 reactions and 155 species in the gas-phase. Anthropogenic emissions are prescribed from reanalysis and CCMI data. Natural emissions of ozone precursors (from lightning, soil and plants) are simulated interactively based on respective measurements and parametrisations (Guenther et al., 2006; Tost et al., 2006; Kerkweg et al., 2006).

4. In line 55, please provide the full name of MESSy, where it is first introduced.

We add the full name: '(Modular Earth Submodel System)'.

5. From Lines 105 to 115, it is not clear what are inputs and outputs from the listed equation. It states (L154) that "The two schemes are combined afterwards to yield a smooth function for An" and then (L108)" to yield the stomatal conductance (gs)". Is An used to calculate gs after An is derived from Am?

We modify line 99 ff. accordingly referring to more details in the supplement section 1.

Further details of the calculation are provided in the manuscript supplement.

We add to the supplement:

According to the established IFS model, A_n is derived from the saturation level A_m (among others) and is used for the calculation of g_s afterwards. The calculation of the net assimilation rate (A_n) distinguishes for a CO_2 limiting and the radiation limiting regime which changes at level A_m (from radiation to CO_2 limiting regime):

$$A_m = A_{m,max}\left[1 - \exp(-g_m(C_i - \Gamma)/A_{m,max})\right] \tag{1}$$

The maximum photosynthetic capacity $A_{m,max}$ is calculated as follows:

$$A_{m,max}(T_s) = \frac{A_{m,max}(25)Q_{10Am,max}^{(T_s-25)/10}}{(1+e^{0.3(T_{1am,max}-T_s)})(1+e^{0.3(T_{2am,max}-T_s)})} \tag{2}$$

with $T_{1am,max} = 8°\mathrm{C}$, $T_{2am,max} = 38°\mathrm{C}$ and $A_{m,max} = 2.2mg(CO_2)m^{-2}s^{-1}$. The mesophyll conductance g_m is calculated:

$$g_m(T_s) = \frac{g_m(25°C)Q_{10gm}^{(T_s-25)/10}}{(1+e^{0.3(T_{1gm}-T_s)})(1+e^{0.3(T_{2gm}-T_s)})} \tag{3}$$

with $T_{1gm} = 5°\mathrm{C}$ and $T_{2gm} = 36°\mathrm{C}$. T_s is the leaf surface temperature (here 2m temperature) and the Q_{10} constant is 2. $g_m(25°C)$ depends on soil moisture and is further described in ECMWF (2021). An exponential transition function represents A_n in dependence on radiation and A_m.

6. The temperature dependence of gm is highly variable. What function is used to describe gm and why in your model?

This aspect is addressed in the extended model description above.

7. Line 119 how do you implement the water stress function into the stomatal conductance? Please provide the used function here.

We add to line L.121/122.

[...] which are given in Sec. S1 of the supplement.

To supplement section S1, we add:

According to Calvet et al. (1998, 2004) plants respond in the a complex way through the mesophyll conductance (g_m) to soil moisture stress:

$$g_m(25°C) = g_m^N \frac{f(W_s)}{W_{crit}} \tag{4}$$

$$g_m(25°C) = g_m^N + g_m^0(25°C)\frac{f(W_s) - W_{crit}}{1 - W_{crit}} \tag{5}$$

where $g_m^0(25°C)$ is a species-dependent parameter (here: 25 $mm\ s^{-1}$). g_m^N is the stressed value of g_m and described in ECMWF (2021).

8. Figure 2 How the Am,max is derived? It seems unrealistic in central Australia and southern Africa where most of the area is desert with low photosynthesis but model predictions of Am,max are high in those regions in panel a.

We refer in line 250 to the (newly added) formula of $A_{m,max}$ in the supplement. Line 254, we extend the following:

[...] which depends on the model vegetation mask. $A_{m,max}$ is strongly driven by leaf (2m) temperature which is reflected by the distribution plot in Fig. 2a.

9. Line 344, delete "to"

In line 344, we only find 'the' needless and deleted it.

10. Line 372 Please elaborate on the correlation between stomatal conductance and photosynthesis and how the change in CO2 concentration will affect the stomatal conductance and photosynthesis differently.

We a add the following in line 400:

ECHAM/MESSy does not simulate an interactive carbon cycle, namely the photosynthesis i.e. the net assimilation of CO_2 is calculated for simulating the stomatal conductance with a first order dependence scaled by the CO_2 deficit between plant cavity and atmosphere. Several studies reported that an increase of atmospheric CO_2 reduces the leaf stomatal conductance varying from 50 % in dense meadows, to 15 % in broad-leaved forests, and to less than 10 % in coniferous forests. This response is non-linear because the CO_2 stimulation of photosynthesis saturates at high atmospheric CO_2. (Vicente-Serrano et al. (2022) and references therein).

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