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Reply on RC2

Marcus Breil et al.

Author comment on "The response of the regional longwave radiation balance and climate system in Europe to an idealized afforestation experiment" by Marcus Breil et al., Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2022-51-AC2, 2023

Referee #2

This study used regional climate model to simulate the biogeochemical (change in atmospheric CO2) and biogeophysical (change in land surface characteristics) effects of afforestation over the whole Europe continent. The authors found that the biogeophysical effect dominates biogeochemical effect in regulating surface temperature, and idealized afforestation would lead to a net warming over Europe. This study focused on the analysis of longwave radiation budget change due to afforestation, and found that changes of temperature and water vapor due to biogeophysical effect play an important role in the regional greenhouse effect. I have the following comments:

- We thank the reviewer for the assessment and the helpful comments on our manuscript. Detailed answers to the comments can be found below. The changes in the revised manuscript have been implemented with tracked changes.

Lines 79-81: This description is not accurate. For example, the modeling study of Bala et al. (2007) considered the complex biogeophysical effects including changes in longwave radiation, but just did not focus on the longwave radiation budget.

- We thank the reviewer for pointing this out. It was not our intention to state that longwave radiation processes are not included in these studies. We just rather wanted to emphasize that the effects of the biogeochemically induced CO2 reduction and of the biogeophysically induced albedo changes are generally highlighted in the studies. Therefore, the sentence was modified as follows:

'In general, studies mainly emphasize the effects of the biogeochemically induced CO2 reduction and the biogeophysically induced changes in the albedo (Claussen et al., 2001; Bala et al, 2007).' (lines 80-82).

Line 110: Please elaborate a bit on how the spun-up simulation is performed.

- We extended the description of the RCM simulation with the following statement about the spin-up procedure:

'For this spin-up, CCLM-VEG3D was again driven with ERA-Interim reanalyses for the period 1979-1985, whereby the same model setup was used as for the period 1986-2015. The simulated conditions in the soil and in the atmosphere at the end of the spin-up period were then used as initial conditions in the long-term simulation' (lines 111-114).

Lines 114-115: When the reduced CO2 concentration is applied to FOREST and GRASS simulations, is CO2-induced climate change feedback considered?

- In our study, we analyze the effects of an idealized afforestation on the regional longwave radiation balance in Europe by means of Regional Climate Model simulations. In these simulations, fixed boundary conditions are used, which means that CO2 induced global feedbacks cannot be considered. This is now explicitly mentioned in section 2.2:

'Differences in the CO2 concentrations between a grassland continent and historic CO2 concentrations are not considered, in order to enable a direct comparison of the CARBON simulation with the GRASS and FOREST runs, and thus, a consistent decomposition of biogeophysical and biogeochemical effects of afforestation. As a consequence, the CO2 induced global climate feedbacks are not taken into account.' (lines (153-157).

Additionally, we discuss the effects of the missing global CO2 feedbacks on the simulation results extensively in section 4:

'Based on the above, we can assume that an idealized reduction of the global CO2 concentrations to pre-industrial conditions by a regional afforestation would have a global cooling effect, due to the global climate feedbacks described above. A consideration of such colder global climate conditions in our experiment would of course have certain implications on the biogeophysical processes in our modeling domain. For instance, driving the CARBON simulation with generally colder boundary conditions would enhance snowfall during winter in Europe. The snow masking effect would consequently be increased and more solar radiation would be absorbed than with present-day boundary conditions. As a result, the TOA energy balance would be further enhanced in winter. This process is known to be the reason for the general warming effect of afforestation in the high latitudes (e.g. Claussen et al., 2001; Bonan, 2008). Furthermore, more snow accumulation in winter would extend the melting phase in spring and increase the differences in absorbed solar radiation between CARBON and GRASS. Since an increased net shortwave radiation in spring (Fig. 8) is already an important factor for the increased TOA energy balance with afforestation particularly in Scandinavia, the total warming would be intensified.

In addition, the impact of wind sheer on the turbulent heat exchange is getting stronger for colder atmospheric conditions, since buoyance becomes smaller (e.g. Breil et al., 2021). That means that the impact of the surface roughness on Ts also becomes stronger. Since the surface roughness of forests is higher than of grasslands, the summertime cooling effect of afforestation on Ts (Fig. 3b) would be increased and emitted longwave radiation would be further reduced. Therefore, the consideration of global climate feedbacks in our modeling approach and thus, a forcing with colder boundary conditions, would even intensify the increased TOA energy balance and the warming effect of afforestation in Europe. An idealized reduction of the global CO2 concentrations to pre-industrial levels by afforestation would consequently not actually cool the regional climate

in Europe to pre-industrial conditions, as the regionally increased TOA energy balance would counteract the global effect.' (lines 382-405).

Line 147: How about climate change induced by CO2 change? It seems the atmospheric boundary condition does not change with CO2 change here. This issue should be discussed in detail.

- Please see our response to your above comment.

Lines 271-272: '…whether afforestation has in general a warming or a cooling effect on the regional climate in Europe. In order to investigate that, the energy balance at the top of the atmosphere (TOA) is analyzed'. It should be noted that regional climate change also depends on lateral heat transport.

- Thanks for this hint. We rephrased the sentence as follows:

'Since the regional climate conditions in Europe depend decisively both on the lateral heat transport and on the radiative energy input, the energy balance at the top of the atmosphere (TOA) is analyzed to quantify the impact of the latter.' (lines 313-315).

Lines 332-335: The interpretation of the finding of Donohoe et al. (2014) is not right, and actually does not apply to the lack of CO2-induced feedback here.

- The wording of this paragraph was unfortunately misleading. Donohoe et al., (2014) show that the temperature effect of changes in the CO2 concentrations is not mainly caused by direct changes in the longwave radiation balance, but by indirect changes in the shortwave radiation balance. Changes in the longwave radiation balance just set temperature changes into motion, but the main changes in the energy budget of the climate system are caused by indirect climate feedbacks, e.g. ice-albedo feedback associated with changes in the snow and ice cover, which lead to changes in the shortwave radiation balance. However, such feedbacks are not considered in our RCM approach, since fixed boundary conditions are used. This is the reason why only a small temperature effect of a CO2 reduction to pre-industrial levels is simulated in our experiment, much smaller that one could expect from such a strong CO2 reduction. Therefore, we can conclude that our boundary conditions are too warm. In order to clarify this, the paragraph is rephrased in the following way:

'However, the results of our simulations are in line with recent studies providing evidence that the temperature effect of changing CO2 concentrations is not mainly caused by direct changes in the longwave radiation balance, but by changes in the shortwave radiation balance, which are indirectly induced by changes in global CO2 climate feedbacks, e.g. ice-albedo feedback associated with changes in the snow and ice cover (e.g., Donohoe et al., 2014). Since such feedbacks are not included in our experiment, we have to conclude that the driving boundary conditions of our simulations are too warm.' (lines 375-381).