Interactive comment on "What determines the sign of the evapotranspiration response to afforestation in the European summer?" by Marcus Breil et al.

Anonymous Referee #1 Received and published: 10 September 2020

The paper deals with the afforestation effect on evapotranspiration rate (ET) of the European continent. The paper uses a Regional Climate Model COSMO-CLM to compare ET changes due to a scenarios of afforestation of the whole European landscape. Five different variables, that are dependent on three land cove types (two forests types and grassland) are used in the model to deduce the ET rate per unit area for the continent. The model finds that what mainly governs the ET rate in the summer time is the water saturation difference between the ecosystem surface and the above air. In southern Europe, where solar radiation burden is high, grassland ecosystem ET is higher than forest ET because the grassland surface temperature is higher than that of the forest ecosystems, thus the water deficit there is higher. In northern Europe, forests ET is higher and this due to higher absorb radiation by the forest ecosystem, while a small surface temperature difference exists between the different ecosystem types. It is an interesting, conceptual paper that tries to help resolving an ongoing question of the effect of land cover change on ecosystems ET rate, in particularly by the change from a grassland to a forest ecosystem across a wide climatic conditions. As such the paper is within the scope of the journal and of high interest for wide disciplinary communities. However, I find two major weak points in the paper that require serious revisions:
- Thanks for your assessment. We hope that we are able to respond satisfactorily to your comments and clear the open issues you raised.

1. Model results vs. ground base measurements results. As the authors rightly wrote, based mainly on runoff measurements, forest ecosystems ET are mostly higher than grass ecosystems ET and the differences are functions of many variables, partially presented by the authors. Based on what I am familiar with, in most (if not all) Mediterranean dryer parts, summer ET in forest is higher than that of any paired grasslands sites. See, for example, papers on California (Ryu, et al., 2008, and Baldocchi et al., 2009) and for the Eastern Mediterranean region (Rohatyn, 2018), which seem not to agree with the paper main results. An important part of the explanation for the lower ET in grassland ecosystems in summer in such regions, is that the grassland is mainly annuals, which are dying toward the summer while the trees keep evaporating all year long. This is likely the adaptation of annuals grassland plant types to the regional dry climatic conditions. In wetter regions, the ET difference, based on FluxNet data, are less pronounced, and the paper is in agreement with studies that show that the ET differences depends on local conditions. This leads to the next comments.
- We agree, that a lot of observation-based studies indicate higher ET rates of forests in comparison to grasslands in Mediterranean regions. In the revised manuscript, this issue is pointed out more clearly.

Lines (346-351):
"In this context, the simulated increase in evapotranspiration with afforestation for large parts of Central and Northern Europa are in line with observations (e.g. Duveiller et al., 2018), while the simulated reduction in evapotranspiration in the Mediterranean is not reflected by observations (e.g. Rohatyn et al., 2018). One potential explanation for these deviations between the CCLM-VEG3D model results and observations is the missing consideration of summertime senescence of grasslands in Mediterranean regions and the associated reduction in grassland evapotranspiration (Ryu et al., 2008)."

However, a direct comparison of observational data with our model results is difficult, due to the different spatial scales of the data. While observational data reflect the local differences between forest and grassland transpiration rates, in our simulation setup, large-scale forestation scenarios are applied to analyze the general transpiration responses to forestation in an idealized and isolated way. It is therefore very difficult to assess the model results quantitatively and qualitatively.

Lines (379-384)
“However, a direct comparison of the CCLM-VEG3D model results with observational data is generally difficult, due to the different spatial representativity of the data. While observational data (satellite data as well as data from eddy covariance flux towers) reflect the local transpiration responses to forestation (Bright et al., 2017), in the CCLM-VEG3D simulation setup, large-scale forestation scenarios are applied to analyze the general transpiration responses to forestation in an idealized and isolated way. Therefore, it is difficult to assess the CCLM-VEG3D model results quantitatively and qualitatively in comparison to observations”

Furthermore, the aim of the study is not to reproduce observed transpiration rates. We rather want to understand the reason for the contradicting evapotranspiration responses to forestation existing in observations and model results. In this context, we are able to introduce a physically consistent explanation for this phenomena, in which the evapotranspiration responses are described as an interplay of two factors, namely the reduced vapor pressure deficit in forests facing their evapotranspiration facilitating biogeophysical characteristics. Since the weighting of both factors is differently pronounced in each model, and furthermore, depends on latitude and forest type, deviating evapotranspiration responses are observed and simulated. Thus, in comparison to observations, it seems that in our model the weighting of both factors is not absolutely correct for the Mediterranean (as far as we can assess it, regarding the different spatial scales). This aspect is also further emphasized in the revised manuscript

Lines (374-378):
“Since this weighting is model-specific, slightly different evapotranspiration responses of forests and grasslands are anticipated for different model simulations. This can also be expected for observed evapotranspiration rates, since the biogeophysical characteristics of forests and grasslands vary also in nature (Garratt, 1993; Henderson-Sellers, 1993; Schenk and Jackson, 2003), potentially explaining differences between the CCLM-VEG3D results and observations, especially in Southern Europe (Rohatyn et al., 2018).”

2. Comment for the conceptual aspects.
a. As the Authors rightly mention, vegetative ecosystem is much more complicated than described by the 5 parameters present in Table 1. However, it seems, there are several important mechanisms that could override the dominant effect of the increase in water saturation deficit presented by the paper. Ranking the importance of the different mechanisms, function of the local climatic conditions, on plants types, its ages, its density, soil conditions, are avoided. Among those important factors, there is insufficient consideration in the paper of factors such as: the phenology effects (e.g., the annuals life span; see above), the structural effects on the transpiration rate (trees are multi–layers, which has an effect on the leaf to air temperature difference and VPD within the canopy, on light intensity, and more), the understory contribution to the ecosystem ET, etc. Obviously, the model cannot include all of these effects, but should at least be discussed, with respect to the difference between the model finding and measurements results, and to provide possible explanations, and possibly how to better simulate these additional factors.
- you are right, VEG3D does not include these effects and thus, is not able to reflect the whole complexity of the soil-vegetation-atmosphere system. In the revised manuscript these model deficiencies and their potential impact on the differences to observations are discussed in more detail.

Lines (314-319):
"Climate simulations with incorporated Land Surface Models (LSMs) are an appropriate method to analyze the reasons for these varying evapotranspiration rates of forests and grasslands. However, models constitute only a simplified description of reality and thus, cannot represent the complex biogeophysical processes in nature comprehensively. For instance, VEG3D does not consider the effects of the multilayer canopy structure of trees (effects of shaded and unshaded leaves; Bonan et al., 2012) or the influence of the understory on evapotranspiration rates, which can contribute substantially to total evapotranspiration in forests (e.g. Yepez et al., 2003)."

Lines (348-351):
"One potential explanation for these deviations between the CCLM-VEG3D model results and observations is the missing consideration of summertime senescence of grasslands in Mediterranean regions and the associated reduction in grassland evapotranspiration (Ryu et al., 2008)."

b. Feedbacks between the vegetation and the atmosphere. It should be possible for a paper, where the results are based on a regional climatic model (COSMO), to discuss some vegetation-atmosphere feedbacks. For example, it is shown that the sensible heat flux is higher at the southern parts of the continent, this should dry the air and raises its temperature and may increase the leaf to air VPD for the forest model runs. Or, what is the effect of the higher ET (by the grass) on cloudiness and Rn? Referring to such effects could be of a valuable to such model-based paper.
- you are right. Since sensible heat fluxes are increased in the FOREST simulation, air temperatures are increased and in this way also the capability of the atmosphere to carry water vapor (Breil et al., 2020). But due to the intense vertical mixing within the boundary layer and the associated increased heat capacity of the atmosphere in comparison to the surface, the warming of the atmosphere is less pronounced than the cooling of the surface in the FOREST simulation. The vapor pressure deficit is consequently all over Europe reduced in FOREST, although sensible heat fluxes are increased.
Furthermore, we agree that evapotranspiration changes can affect the cloud cover and thus, the net short-wave radiation. This feedback is now discussed in detail in the revised manuscript.

Lines (266-273):
"Differences in evapotranspiration as seen for the FOREST and GRASS runs (Figure 2), inevitably affect the atmospheric conditions in these simulations. For instance, the increased evapotranspiration rates in Northern Europe in FOREST lead to an increased cloud cover in this region (Figure 5a). The incoming solar radiation is consequently reduced in comparison to GRASS. However, since the albedo of the trees in the FOREST simulation is lower than the albedo of grassland in the GRASS run, the reduction of the incoming solar radiation is compensated and net short-wave radiation is slightly increased in Northern Europe (Figure 5b). For the rest of the European continent, this albedo effect is even stronger pronounced and the net short-wave radiation is considerably increased, since cloud cover is not changed compared to GRASS. But this increased radiative energy input does not result in higher surface temperatures"

Lines (282-285):
"Due to the increased evapotranspiration rates in ROUGH in Northern Europe (Figure 2b), cloud cover is increased in this region in comparison to the FOREST run (Figure 5c). The net short-wave radiation is consequently slightly reduced (Figure 5d). But for the rest of the European continent, net short-wave radiation in FOREST and ROUGH is on the same high level, due to the unchanged albedo values."

Minor comments:
1. Since the effect of higher ET by forest is a puzzle for most readers and the explanation is through the higher surface temperature of the grass ecosystem, it is suggested to move this text to an earlier

part of the results section, including Fig.5 b & e. Does the model calculate the leaves' skin temperature, and if so, how?

- Thanks for your suggestion, but we would like to maintain the current structure to keep the logical order of the manuscript.

Yes. The leaf temperature is calculated by solving the energy balance of the vegetation layer iteratively.

2. The paragraph, starting in line. 163 is unclear.

- paragraph is rephrased.

"In Southern and Central Europe, evapotranspiration is reduced in the FOREST run compared to the GRASS simulation (Figure 2a). The evapotranspiration reduction in FOREST is in this context particularly strong in Southern Europe. But in Northern Europe the opposite is the case and evapotranspiration is increased in FOREST. In Central Europe, regions with reduced evapotranspiration rates in FOREST coincide with regions covered by deciduous forest (Figure 1). This indicates that differences in evapotranspiration rates between forests and grassland are affected by the prevailing forest type in a region. Thus, the different vegetation characteristics (a-f) of deciduous and coniferous forest, must have an impact on the intensity of the evapotranspiration response to afforestation. But since both forest types have lower resistance values (higher *c* values) than grasslands, both forest types should also stronger promote transpiration than grasslands, which seems to be in contradiction to the reduced evapotranspiration rates of deciduous forests in Central Europe. Therefore, the resistance values of the different forest types cannot solely explain the opposing transpiration signals."

3. Line 182. It is likely that soil ET rate is affected by soil layers deeper than 5 cm. This sentence is questionable. And for line 187 - the soil contribution to ET could be very important (up to several ten percent of total ET).

- we agree, it is possible that soil depths deeper than 5 cm can be affected by soil evaporation, but the contribution is decreasing with depth. A depth of 5 cm is therefore a meaningful reference to evaluate the contribution of soil evaporation to total evapotranspiration. Furthermore, you are right, in general, the contribution of soil evaporation to total evapotranspiration can be very important. Both statements are therefore specified in the revised paper.

Lines (199-201):

"Differences in the upper 5 cm of the soil (Figure 3b) are used as an indicator for differences in the soil evaporation, since this process is executed through the soil surface (although soil evaporation can also be affected by soil depths deeper than 5 cm)."

Lines (205-206):

"The contribution of soil evaporation to total evaporation is therefore low in both simulations"

The important message of this comparison is that the contribution of soil evaporation to the total evapotranspiration does not differ between FOREST and GRASS and, therefore, differences in the evapotranspiration rates must be caused by differences in the transpiration rates.

4. Figure 3, units for the soil humidity values are unclear. Also note that part 'c' is noted twice in the caption (instead of 'd').

- units are changed in [%] and the caption is revised.

5. Figure 4 units are unclear.

- units are clarified in the caption.

6. To better understand the different effecting parameters on ra and rc between the ecosystems types it is suggesting to add Wwilt and Wroot values to table 2.

- W_{wilt} is the permanent wilting point and depends on the soil type. Therefore, W_{wilt} is in in each grid point identical in all three simulations. W_{root} is the water content within the rooted soil depth. This quantity is different at each grid point and changes at each time step of the simulation. Thus, it is from our point of view not meaningful to include these quantities in table 2.

Papers:

Rohatyn, S., et al. (2018). "Differential Impacts of Land Use and Precipitationon "Ecosystem Water Yield"." Water resources research 54(8): 5457-5470.

Baldocchi Dennis, Qi Chen, Xingyuan Chen, Siyan Ma, Gretchen Miller, Youngryel Ryu, Jingfeng Xiao, Rebecca Wenk and John Battles (2009). “The Dynamics of Energy, Water and Carbon Fluxes in a Blue Oak (Quercus douglasii) Savanna in California,USA”, in: “Ecosystem Function in Global Savannas: Measurement and Modeling at Landscape to Global Scales” – edited by Michael J. Hill and Niall P. Hanan, CRC/Taylor and Francis.

Ryu Youngryel, Dennis D. Baldocchi, Siyan Ma and Ted Heh (2008), “Interannual variability of evapotranspiration and energy exchange over an annual grassland in California”, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 113.