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

Anonymous Referee #2
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The authors have identified an important, and poorly understood, aspect of the effects of afforestation/deforestation in temperate latitudes on climate: do forests increase or decrease evapotranspiration (ET) compared with grasslands? Some observational studies suggest forests have greater rates of ET; some show the opposite. Many modeling studies show forests increase ET; others do not. The topic is fraught with confusion. I had hoped this manuscript would clarify the science and provide a strong, insightful understanding of forest ET and the factors controlling ET. However, by using a poorly documented model, and by not adequately describing the model, the rationale for parameterizations and parameter values, and the limitations of the model, the manuscript does not clarify the science and, instead, adds more confusion to the literature.
- thank you very much for your detailed comments. We hope that our responses will help to dissolve potential confusions.

1. I have several concerns about the VEG3D model. From the few equations given in the manuscript, it appears to be a highly simplified land surface model. There is nothing wrong with that! But I suspect the findings of the study do not extend to more complex land surface models. The authors need to provide a thorough description of the model, justify the parameterizations used in the model, and justify parameter values. They also need to discuss how the simplifications of VEG3D might limit the generality of the results. This is not the first time this issue has arisen. VEG3D was used in a previous study by the lead author:

Breil, M., and Coauthors, 2020: The Opposing Effects of Reforestation and Afforestation on the Diurnal Temperature Cycle at the Surface and in the Lowest Atmospheric Model Level in the European Summer. J. Climate, 33, 9159–9179

In full disclosure, I was a reviewer of that manuscript and noted in my review thatVEG3D is a poorly documented model, is not widely known by the scientific community, and has not been tested in temperate forest/grassland simulations in comparison with flux tower measurements. That does not mean that the model is deficient or in-appropriate for this study, but the description of ET provided in the current manuscript reveals some non-standard formulations in the model that likely limit the generality of the results.
- in the revised version of the manuscript, the applied parameterizations and parameter values are discussed in more detail (see answers to the following comments).

1a. The authors describe the aerodynamic resistance ra used in the transpiration equation (eq 3). This is not a standard formulation of aerodynamic resistance (I have never seen it before). The resistance depends on wind speed at the top of the canopy, leaf area index, and some undescribed parameters. Classic textbooks on micrometeorology and boundary layer meteorology formulate the resistance using integrated flux-profile relationships between the apparent source/sink in the canopy (at a height equal to the roughness length [z0] plus displacement height [d]) and the lowest model level in the atmosphere

[z]:ra = [ln(z-d)/z0]ˆ2 / (kˆ2 * u)

u is wind speed at z. Depending on the specific model, z0 can be either that for momentum or for scalars, and ra is adjusted for atmospheric stability. What is the justification for eq 3, which seems to go back to two very old papers (Deardorff, 1978; Taconet et al., 1986)? Why is this equation used rather than classic boundary layer theory? It seems from eq 3 that roughness length only enters the model through wind speed at the top of the canopy (uaf), but there is no equation for uaf. It appears to go back to Goudriann's old work. This is very important, because the key outcome of the study is that surface roughness is the primary difference between forests and grasslands. Readers must understand precisely how surface roughness is used in the model and why particular formulations are used in the model.

- we are sorry that Eq. (3) caused that much confusion. This is exactly the opposite of what we intended, by using a simple description of r_a. We thought that this formulation would keep the section clear and understandable. Obviously, this was not the case. The description of r_a is therefore refined as follows:

Lines (86-105):

"In r_a, the turbulent atmospheric conditions for the transfer of water vapor are reflected, which are calculated by means of an empirical parameter C_{leaf} and the friction velocity u*:

$$r_a = \frac{C_{leaf}}{u*} \qquad \text{Eq. (3)}$$

C_{leaf} describes an empirical interrelation between the turbulent exchange and the Leaf Area Index (LAI) (Taconet et al., 1986), in relation to the leaf geometry, represented by the plant specific parameter c_{veg} (a) (Goudriaan, 1977):

$$C_{leaf} = \frac{1 + 0.5 * LAI}{0.04 * LAI * c_{veg}} \qquad \text{Eq. (4)}$$

u* is classically derived from the Monin-Obukhov Similarity Theory (Monin and Obukhov, 1954) and as such mainly dependent on z_0:

$$u* = k \frac{\left(v_{z_a} - v_{z_0}\right)}{\ln\left(\frac{z_a}{z_0}\right) + \Psi\left(\frac{z_a}{L*}\right) + \Psi\left(\frac{z_0}{L*}\right)} \qquad \text{Eq. (5)}$$

where z_a is the height of the lowest atmospheric model level and z_0 is the roughness length. v_{za} and v_{z0} are consequently the wind velocities at the respective heights. k is the Karman-constant. $L*$ is the Monin-Obukhov length and Ψ is a stability-function according to Businger et al., (1971), establishing empirical relationships in turbulent motion, which depend on the atmospheric stratification. According to Goudriaan (1977), r_a and consequently its contribution to the transfer coefficient c, is primarily influenced by one vegetation parameter: the surface roughness (b)."

In comparison to the previous version, it is shown that r_a depends on u* and the empirical parameter C_{leaf}, representing an empirical interrelation between the turbulent exchange and the Leaf Area Index (LAI), in relation to the leaf geometry. The calculation of r_a is therefore totally in line with the classic boundary layer theory.

In connection with the empirical C_{leaf} parameter, a plant specific parameter c_{veg} is now introduced, representing the leaf geometry. This parameter was not mentioned in the previous version of the manuscript, since its impact on r_a is small in comparison to the surface roughness (Goudriaan, 1977). But due to the refinement of this section, this parameter is now additionally introduced and discussed in the course of the manuscript.

Admittedly, the description of the empirical vegetation parameter C_{leaf} is not the latest one. But this does not mean that the produced results are not valid. On the contrary; within the scope of several model-intercomparison studies, it could be demonstrated that VEG3D produces comparable results to more recent LSMs (e.g. Davin et al., 2020; Breil et al., 2020; Krinner et al, 2018).

1b. The formulation of canopy resistance to transpiration (eq 4) is also somewhat odd. It goes back to an equation in Deardoff (1978), in which canopy resistance depends on a specified minimum resistance that is modified for solar radiation and soil moisture. Most current-generation land surface models use an approach that couples photosynthesis and stomatal conductance through the Farquhar et al. (1980) photosynthesis model and semi-empirical stomatal conductance models such as proposed by Ball-Berry or Medlyn. In addition to light and soil moisture effects on stomatal conductance, those models also include temperature and vapor pressure deficit (VPD) effects on stomatal conductance. The VEG3D model ignore those latter two effects. That exclusion greatly limits the generality of the main finding of the study (that VPD, as modified by surface roughness, is a key determinant of differences in ET between forests and grasslands). The response of stomata to VPD is not considered (i.e. stomata close as VPD increases). Nor are the indirect effects of VPD on stomata through leaf temperature considered. Again, readers need to know why eq 4 is used in contrast with more common stomatal conductance models and what the implications of eq 4 are for the main findings of the study.

- You are right, temperature and vapor pressure deficit effects on stomatal conductance are not considered in VEG3D. These particular capabilities of trees can certainly affect evapotranspiration rates in regions with pronounced differences in the saturation deficit between forests and grasslands, like Southern Europe.

Interestingly, the results of model-intercomparison studies show that LSMs, in which these stomatal effects are integrated, exhibit comparable evapotranspiration responses as VEG3D (e.g. Davin et al., 2020). For instance, in the framework of the LUCAS, simulations with the classic model VEG3D and the more sophisticated Community Land Model under the same atmospheric boundary conditions, show similar spatial patterns of increased or reduced evapotranspiration rates with afforestation (Davin et al., 2020).Thus, the differences in the model complexity (effects of shaded and unshaded leaves or the vapor pressure dependency of stomata closure) cannot be the main reason for the simulated differences in evapotranspiration responses of forests and grasslands. These different evapotranspiration responses must rather be caused by a fundamental mechanism, which is simulated in both, classic as well as complex LSMs. This is now emphasized in the manuscript.

Lines (34-37):

"According to our present knowledge about the biogeophysical effects of forests and grasslands, this increased forest evapotranspiration is caused by deeper roots (Schenk and Jackson, 2003) and a higher Leaf Area Index (LAI, e.g. Henderson-Sellers, 1993) than in grassland, whose influence can be attenuated by a reduced photosynthetic activity of forests and an associated stomata closure (Leuzinger et al., 2005)."

Lines (351-357):

"Another possible reason for the disagreement between the simulation results and the observations is the missing consideration of vapor pressure effects on the stomatal resistance in CCLM-VEG3D. For instance, in Southern Europe the saturation deficit of forests is particularly lower than for grasslands. In contrast to the simulated trees in CCLM-VEG3D, real trees are potentially able to adapt to this lower saturation deficit, by further reducing the stomatal closure and thus the transfer coefficient. In line with the introduced evapotranspiration concept, the transpiration facilitating characteristics of forests (2) would be further enhanced, counteracting the reduced saturation deficit (1) in Southern Europe and thus, would increase forest evapotranspiration."

Lines (314-328):

"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). Furthermore, VEG3D does not consider the impact of temperature and vapor pressure deficit on stomata closure, potentially affecting evapotranspiration rates in regions with pronounced differences in saturation deficit between forests and grasslands. But the results of model-intercomparison studies show that more sophisticated LSMs, in which these biogeophysical effects are integrated, exhibit comparable evapotranspiration responses to afforestation as VEG3D (e.g. de Noblet-Ducoudré et al. 2012; Davin et al., 2020). For instance, in the framework of the LUCAS project, simulations with the classic model VEG3D and the more sophisticated Community Land Model under the same atmospheric boundary conditions, show similar spatial patterns of increased or reduced evapotranspiration rates with afforestation (Davin et al., 2020). Thus, the differences in the model complexity (effects of shaded and unshaded leaves or the vapor pressure dependency of stomata closure) cannot be the main reason for the simulated differences in evapotranspiration responses of forests and grasslands. These different evapotranspiration responses must rather be caused by a fundamental mechanism, which is simulated in both, classic as well as complex LSMs."

In order to get to the bottom of these fundamental processes, the use of a less complex model can even be beneficial. In such a model, the degrees of freedom are reduced and functional interrelations can consequently be deduced more easily. For this reason, we are able to show in the manuscript that the driving force behind evapotranspiration (saturation deficit) is already reduced in forests (in comparison to grasslands), due to their inherent biogeophysical characteristics (z_0). Depending on latitude and forest type, therefore, forests can have lower evapotranspiration rates than grasslands.

1c. The term (1+0.5*LAI)/LAI is common to both ra and rc. What does this term represent? It seems to be a scaling term for canopy LAI (i.e, from a leaf resistance to a canopy resistance). Aerodynamic resistance is commonly expressed per unit ground area. Why does ra need to be scaled by LAI?

- This term represents an empirical interrelation between the turbulent exchange and the vegetation specific characteristics *LAI* and the leaf geometry (Taconet et al., 1986). The term accounts for the fact that the turbulent exchange is proportional to the LAI with a low exchange for small LAIs and an increasing exchange with increasing LAI (but the interrelation has an upper limit; 0.5).

2. The authors emphasize that differences between forest and grassland arise in terms of five model parameters: surface roughness, albedo, root depth, leaf area index, and minimum stomatal conductance.

2a. The justification for several parameter choices goes back to papers by Garratt (1993) and Henderson-Sellers (1993). There has been a lot of model development since then. How do these parameter choices compare with values used in the current generation of land surface models?

- the used model parameters in VEG3D are very similar to the parameters used in other Land Surface Models as it is shown in Breil et al., (2020) (see table below). The albedo and z_0 values are totally in line with the values in other models. The LAI values in VEG3D are higher than in the other models. But the relative LAI differences between the different land use classes (coniferous forest, deciduous forest, grassland) are again comparable. For instance, the relative difference in the contribution of the LAI to r_a (caclulated via Eq. (4)) between coniferous and deciduous forest is 0.97 in VEG3D. If one would use instead the LAI values used in the Community Land Model (CLM), the relative difference would be 0.96. A similar picture is drawn for the relative differences between coniferous forests and grasslands. In VEG3D, the relation is 0.81, while the use of the

CLM values would result in a relation of 0.83. Thus, it can be stated that the parameter values in the respective LSMs lead to comparable physical dependencies.

TABLE 1. Surface roughness z_0, leaf area index (LAI), and surface albedo α in summer (yearly maximum) used in each LUCAS-Ensemble member for needleleaf evergreen trees (NET), broadleaf deciduous trees (BDT), and C3-type grassland (C3).

	z_0			LAI			α		
	NET	BDT	C3	NET	BDT	C3	NET	BDT	C3
WRF-NoahMP	1.09	0.8	0.12	4	4.7	3.5	0.11[a]	0.13[a]	0.23[a]
WRF-CLM4.0	0.7	0.83	0.048	3.75	3.38	2.38	0.11[a]	0.13[a]	0.21[a]
CCLM-VEG3D	1	0.8	0.03	9	8	4	0.11	0.15	0.2
CCLM-TERRA	1	1	0.03	8	6	4.5	0.1	0.15	0.2
CCLM-CLM4.5	0.7	0.83	0.048	3.75	3.38	2.38	0.11[a]	0.13[a]	0.21[a]
REMO-iMOVE	1.4	1	0.05	5	5	3	0.155	0.175	0.21

[a] Calculated for an exemplary leaf/stem ratio.

2b. Table 2 shows only a small difference in rmin between forest and grassland, and no difference between coniferous and deciduous forest. What is the justification for the parameter values? Are there physiological measurements that support them? The values for rmin are very important to the results of the study. The relative contributions of aerodynamic resistance and canopy resistance to total resistance determine the model sensitivity to roughness length. The fact that rmin is similar for all vegetation precludes physiological differences in stomatal conductance from determining differences in ET.

- the parameter values used in VEG3D are based on the results of several studies (see figure below from the review paper of Garratt (1993)). The range of r_{min} values is, in this context, quite large for the different land use types. Therefore, in VEG3D an average r_{min} value is used for each vegetation type. In general, r_{min} values of forests are smaller than r_{min} values of grasslands. r_{min} values of coniferous forests are on the same level as r_{min} values of deciduous forests. The generally lower r_{min} values of forests in comparison to grasslands are an important point in the study. Due to this, r_{min} of forests also facilitates transpiration as the other vegetation specific characteristics do in VEG3D and thus counteracts the reduced vapor pressure deficit.

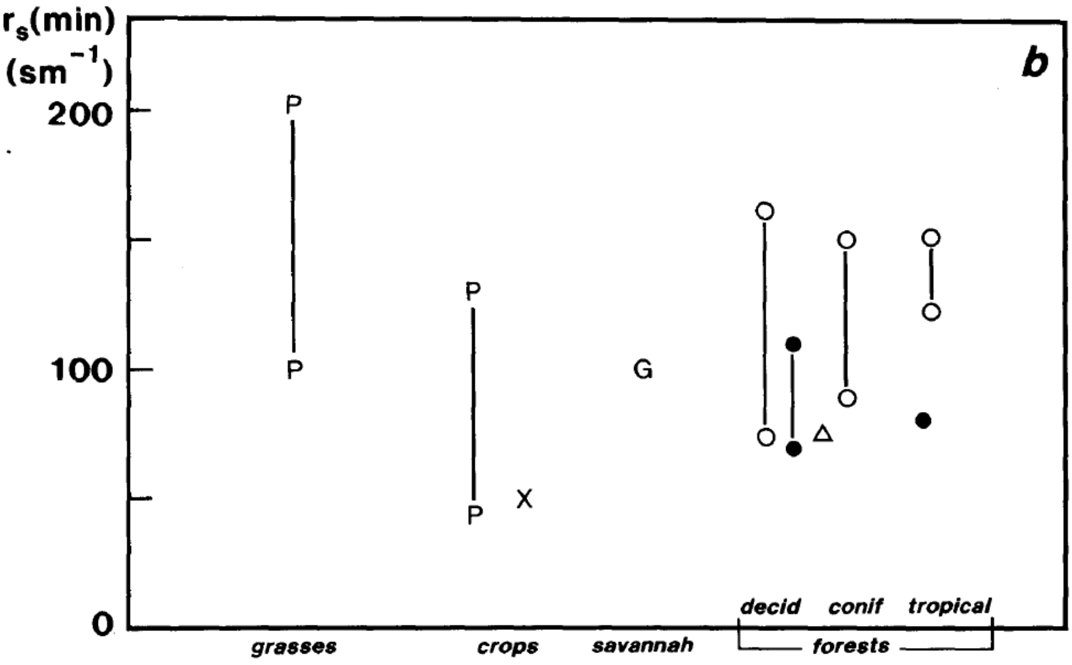

FIG. 4. Variation of unconstrained stomatal resistance r_s^* and minimum surface resistance r_s(min) with vegetation type, based on observations, literature values and model-specified values. Symbols are as follows: (a) (○) from Dorman and Sellers (1989); (●) from Shuttleworth et al. (1984b) for 3 forest sites; (×) from Sellers and Dorman (1987) for barley; (N) from Noilhan and Planton (1989) for maize (showing a wide range in resistance), oats (anomalously high) and a pine forest; 1) barley, 2) wheat, 3) maize, 4) spruce forest are all from Sellers and Dorman (1987). (b) (○) from Dorman and Sellers (1989); (●) from Shuttleworth et al. (1984b); (×) from Sellers and Dorman (1987) for maize; (△) from Sellers and Dorman (1987) for spruce; (G) from Garratt (1978) for subtropical savannah; (P) from Perrier (1982).

2c. No details are given on how root depth affects transpiration, or how the root depth parameter is used in the model. The root depth of deciduous forest is twice that of coniferous forest. Is this the reason for the differences between deciduous and coniferous forests when they are converted to grassland?

- Thanks for raising this important aspect. As described in section 3.2, differences between coniferous and deciduous forests are caused by the lower c value in deciduous forests in comparison to coniferous forests (statement with respect to Central Europe, where opposing evapotranspiration responses occur between coniferous and deciduous forest for the same latitude and vapor pressure deficit).

Both forests types have higher c values than grassland. Since the vapor pressure deficit is in Central Europe for both forest types smaller than for grassland (and thus the driving force for evapotranspiration), the c value of coniferous forest must be higher than the one of deciduous forest, leading to higher ET in coniferous forests and lower ET in deciduous forests in comparison to grasslands. Deeper roots (as for deciduous forests), lead in times of a reduced water availability to increased c values. So if the root depths would be the reason for the different responses, deciduous forests should have higher ET than coniferous forests. Thus, the impact of the root depths on the c calculation must be smaller than the impact of e.g. the albedo and the LAI (albedo is higher and LAI is lower in deciduous forest and the c values consequently smaller). This discussion is now included in the manuscript.

Lines (244-258):

"In Central Europe, the saturation deficit in the FOREST run is comparable to Northern Europe. But in contrast to Northern Europe, regions of increased evapotranspiration are simulated as well as regions of reduced evapotranspiration compared to the GRASS simulation (Figure 2a). As already mentioned in section 3.1, the regions of increased evapotranspiration coincide with regions covered by coniferous forests, while regions of reduced evapotranspiration are covered by deciduous forests. Since the saturation deficit reduction in the FOREST run is comparable for both forest types in Central Europe (Figure 4a), these different evapotranspiration responses to afforestation must be associated with differences in the transfer coefficient c (Eq. 1). The transfer coefficient c of coniferous forest must therefore be higher than the one of deciduous forest. In a coniferous forest LAI is increased and albedo is reduced in comparison to a deciduous forest, while in deciduous forest the root depth and c_{veg} are increased. Thus, both forest types have characteristics which lead to high c values. However, since evapotranspiration in Central Europe is higher for coniferous forests than for deciduous forests, the impact of LAI and the albedo (pronounced in coniferous forests) on c must be higher than the impact of the root depth and c_{veg} (pronounced in deciduous forests). As a result, the impact of the higher transfer coefficient c of coniferous forests surpasses the effects of the lower saturation deficit in Central Europe in the transpiration flux calculation and evapotranspiration is increased, while for deciduous forests the impact of the reduced saturation deficit is dominating and evapotranspiration is reduced."

We are absolutely aware that these parameter values are associated with uncertainties and that the use of only two different forest types is simplified. Therefore, we do not intend to assess the transpiration rates of individual forest types. The aim of this study is to explain the different evapotranspiration rates of forests and grasslands in a physically consistent way. In this context we can show that the evapotranspiration response generally depends on the forest characteristics (without assessing specific forest types).

2d. No details are given for albedo. What is the radiative transfer parameterization in the model? Land surface models typically simulate radiative transfer for visible and near-infrared wavebands and for direct and diffuse radiation. Albedo is a complex result of leaf and stem reflectances, leaf and stem area index, solar zenith angle, and soil moisture. Because only a single albedo is listed as a parameter in Table 2, this makes me think there is no such complex radiative transfer

parameterization in VEG3D and instead the model uses a bulk surface albedo that is prescribed as a parameter. Readers need further information.
-You are right, in VEG3D a bulk approach is used for the albedo. This is clarified in the revised manuscript (Lines 115-116).

3. A striking aspect of Figure 2 is the difference between coniferous and deciduous forests when replaced with grassland. Summer latent heat fluxes are larger in coniferous forest compared with grassland but are smaller than grassland in deciduous forest. This pattern is universally consistent throughout the domain, except for southern Spain and Turkey (smaller latent heat fluxes compared with grassland in a mostly coniferous forest region). The authors acknowledge the influence of forest type (lines165-166), but for the most part discuss their results in terms of Northern Europe versus Southern/Central Europe. For example, the authors frame their conclusions as: "In Northern Europe evapotranspiration is increased with afforestation, in Southern and Central Europe evapotranspiration is decreased" (lines 261-262). The differing results of coniferous and deciduous forests are not even mentioned in the abstract. I would like to see more of a discussion of coniferous versus deciduous forests.
- thanks for this suggestion. A central message of this study is that the interplay between factor 1 (vapor pressure deficit) and factor 2 (high c values due to transpiration facilitating characteristics of forests) is controlled by two determinants. These are the latitude (Lines 337-348) and the forest type (Lines 358-369). This is also stated in the last sentence of the abstract (Line 27). Apparently, we were not able to express this clearly in the manuscript. Therefore, we add some discussion to our original statements.

Lines (244-258):
“In Central Europe, the saturation deficit in the FOREST run is comparable to Northern Europe. But in contrast to Northern Europe, regions of increased evapotranspiration are simulated as well as regions of reduced evapotranspiration compared to the GRASS simulation (Figure 2a). As already mentioned in section 3.1, the regions of increased evapotranspiration coincide with regions covered by coniferous forests, while regions of reduced evapotranspiration are covered by deciduous forests. Since the saturation deficit reduction in the FOREST run is comparable for both forest types in Central Europe (Figure 4a), these different evapotranspiration responses to afforestation must be associated with differences in the transfer coefficient c (Eq. 1). The transfer coefficient c of coniferous forest must therefore be higher than the one of deciduous forest. In a coniferous forest LAI is increased and albedo is reduced in comparison to a deciduous forest, while in deciduous forest the root depth and c_{veg} are increased. Thus, both forest types have characteristics which lead to high c values. However, since evapotranspiration in Central Europe is higher for coniferous forests than for deciduous forests, the impact of LAI and the albedo (pronounced in coniferous forests) on c must be higher than the impact of the root depth and c_{veg} (pronounced in deciduous forests). As a result, the impact of the higher transfer coefficient c of coniferous forests surpasses the effects of the lower saturation deficit in Central Europe in the transpiration flux calculation and evapotranspiration is increased, while for deciduous forests the impact of the reduced saturation deficit is dominating and evapotranspiration is reduced.”

Lines (358-369):
“On the other hand, the simulation results show that the balance between factor (1) and (2) is differently pronounced for different forest types. In Central Europe, for instance, deciduous and coniferous forests are showing opposing evapotranspiration responses to afforestation, although they are facing a comparable saturation deficit (1). Differences in the evapotranspiration rates must consequently be associated with differences in the transfer coefficients (2). A deciduous forest, for instance, has a lower LAI and higher albedo values than a coniferous forest (Table 2). The transfer coefficient is consequently lower and factor (2) is becoming weaker. The impact of the saturation deficit (1) is therefore dominating the effects of factor (2) and the transpiration rates of deciduous

forests are reduced compared to grassland in Central Europe. But for coniferous forest, which are facing a similar saturation deficit (1), the impact of factor is increased (2), due to their higher LAI and lower albedo values. The transpiration rates are consequently higher for coniferous forests in this region. These results are also in line with observation-based studies, showing that evapotranspiration rates differ between different forest types (e.g. Brown et al., 2005), whereby higher evapotranspiration rates are generally assigned to coniferous forests (e.g. Teuling, 2018). Furthermore, Marc and Robinson, (2007) showed that also the age of the forest affects evapotranspiration."

As already mentioned in our response to comment 2c, we do not intend to give specific statements about the evapotranspiration rates of individual forest types, due to the uncertainties related to the used parameter values.

3a. What, specifically, are the differences between these forests that cause the results? One generally thinks of coniferous forests as having a more conservative water-use strategy than deciduous forests (seen, for example, in higher stomatal resistance). But both forests have the same minimum resistance. Is the different response related to rooting depth? In their analysis of soil water (Figure 3), the authors suggest it is not but the analysis is not definitive. It would be better to look at the soil moisture stress term in canopy resistance.

- as already mentioned in comment 2c, the different behavior of coniferous and deciduous forests in Central Europe is mainly caused by the higher albedo values and lower LAI values.

In Figure 3, two important features of the FOREST and GRASS simulations can be seen; (1) the contribution of soil evaporation to total evapotranspiration is the same for forests and grasslands and differences in total evapotranspiration must consequently be caused by transpiration, (2) the available amount of soil water for evapotranspiration is higher for forests than for grasslands. Figure 3a shows that this water amount is lower in coniferous forests than in deciduous forests in Central Europe, due to the more shallow roots. As already discussed in comment 2c, this should lead in deciduous forests to a higher c value compared to coniferous forests, if all other vegetation characteristics would be the same. But since albedo is higher and LAI is lower, this effect of the root depths on the c value is compensated.

3b. Are the results consistent with observations? What do flux towers show? What does MODIS ET show (but remember that MODIS ET is a modeled product).

- as discussed in section 4, the model results have comparable features to observations (dependency to the latitude (Li et al., (2015), to the forest type (Teuling, 2018) and the increased evapotranspiration rates in Northern Europe (Duveiller et al., 2018), Lines 345-347; Line 366-369). The validity of a direct and detailed comparison with paired measurement sites is from our point of view limited. In contrast to the local impacts of land use on the evapotranspiration rates as reflected in observations, in our simulations large-scale forestation scenarios are applied reflecting the general and idealized evapotranspiration responses to forestation. This is also true for the comparison with satellite-based data (e.g. MODIS), although general features of such data (e.g. latitude dependency) are reproduced.

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"

Therefore, the aim of our study is rather to introduce a concept of the physical reasons for the deviating evapotranspiration responses of forests and grasslands, than reproducing observed evapotranspiration rates of coniferous and deciduous forests in specific regions.

4. The crux of the study is Figure 4, which shows the difference in saturation deficit between the forest and grassland simulations. Saturation deficit decreases for forests throughout Europe, with a particularly large decrease in latitudes south of about 40N. The authors discuss the results in light of VPD, resistances, and other parameters that affect transpiration (lines 219-234). No data or figures are provided to justify the interpretation. Skeptical readers need to see more evidence that supports the argument if they are to believe the study.
- As stated in Eq. 1, evapotranspiration is controlled by two factors, (1) the vapor pressure deficit and (2) the transfer coefficient c. Since forests have all over Europe a higher c value than grasslands (table 1 and table 2), lower evapotranspiration rates can only be explained by a lower vapor pressure deficit. Regions of higher or lower evapotranspiration rates than grasslands must therefore inevitably be caused by the interplay of both factors.

5. Figure 5d: Why does net shortwave radiation change when roughness length is changed to that of grassland?
- The albedo is identical in the FOREST and the ROUGH simulation. Therefore, differences in the net short-wave radiation must be caused by atmospheric processes. In Northern Europe, the cloud cover is increased in FOREST (Figure 5c in the revised manuscript), due to the higher evapotranspiration rates in comparison to ROUGH and thus, net short-wave radiation is reduced (Figure 5d). In consequence, the temperature reduction in FOREST is comparatively strong pronounced (Figure 6c) and the increase in evapotranspiration is attenuated (Figure 2b). In the revised paper, this atmospheric feedback process is included.

Lines (266-272):
“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.”

Lines (282-288):
“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. The reduced surface roughness in ROUGH reduces all over Europe the sensible heat transport into the atmosphere (Figure 6d). Thus, the high radiative energy is not as efficiently transformed and transported into the atmosphere as in FOREST, with the consequence that the surface temperatures are increased, similarly to the GRASS simulation (Figure 6c).”

6. Lines 288-290: The authors state that "the dependency of the evapotranspiration rates of forests and grasslands on the latitude is also documented in satellite observations (e.g. Li et al., 2015), showing for example higher evapotranspiration rates of grasslands in South-Eastern Europe, while in Central and Northern Europe evapotranspiration is lower than in forests (Duveiller et al., 2018)". Li et al used MODIS ET, which is a modeled product. What did Duveiller et al base their analysis

on? And, remember, that the more striking aspect of Figure 2 is not the latitudinal dependence but the difference between coniferous and deciduous forests. What do observations say about that difference?

- Duveiller et al., (2018) use also MODIS data, which is as you already mentioned not completely observation-driven. Regarding the evapotranspiration differences between coniferous and deciduous forests, therefore, we think that it is the best to rely in this case on direct measurements, such as lysimeter data. Evapotranspiration rates from these data sets are quite in contradiction to satellite/model products. For instance, while satellite/model products assign higher evapotranspiration rates to deciduous forests (Duveiller et al., 2018), direct measurements at lysimeter stations assign higher evapotranspiration rates to coniferous forests (Teuling, 2018).

Lines (366-369):

"These results are also in line with observation-based studies, showing that evapotranspiration rates differ between different forest types (e.g. Brown et al., 2005), whereby higher evapotranspiration rates are generally assigned to coniferous forests (e.g. Teuling, 2018)."

Additional References:

Businger, J. A., Wyngaard, J. C., Izumi, Y., and Bradley, E. F., (1971): Flux-Profile Relationships in the Atmospheric Surface Layer, *J. Atmos. Sci.*, 28, 181–189.

Krinner, G., and Coauthors, (2018): ESM-SnowMIP: assessing snow models and quantifying snow-related climate feedbacks. *Geoscientific Model Development*, *11*, 5027-5049.