Climate Response to Severe Forestation: A Regional Climate Intercomparison Study
Author Response to Anonymous Review #2

Legend:
Reviewer Comment
Author response
Manuscript edit suggested by author

In this paper, the authors applied three regional climate models to simulate the biophysical climate response to severe (full forest minus grass) forestation in North America and Europe. It is found that the temperature and other physical variables response is largely consistent between North America and Europe by using the same model – CRCM5. The winter warming in high latitudes has been primarily attributed to the snow masking effect of increased tree cover in needleleaf, while the summer cooling in lower latitude has been found to be related to the increased evaporative fraction (i.e., ratio of latent heat to total turbulent heat flux) due to increased broadleaf fraction. The authors also made detailed comparisons across three different models. I believe the idea is not new, but the authors did provide reliable results and conclusions. The conclusion may provide basis for potential forestation over the North America. Below lists my comments.

1. Parameter uncertainty might directly affect the biophysical climate response to forestation across the models. In particular, the authors show that the WRF-NOAH model is lack of snow masking effect and has a quite different minimum stomatal resistance for Needleleaf and Grasses as compared to the CRCM-CLASS model. I'd like to push the authors one more step to at least discuss the fidelity of the stomatal conductance parameter in these models.

[Since comments 1 and 2 are closely related, we reply to both comments simultaneously below.]

2. The minimum stomatal resistance for Needleleaf in WRF-NOAH is only half of that in the CRCM-CLASS. What is the possible true value or range of the Needleleaf stomatal resistance in the observations? It looks like that the low stomatal resistance in WRF-NOAH directly contributes to the increased latent heat fluxes and precipitation in boreal North America during the summertime. Therefore, discussion on the possible true value of the Needleleaf minimum stomatal resistance parameter is necessary as it may make large influence on the biophysical climate effects.

The reviewer is right to point out that parameter uncertainty may directly affect the biophysical climate response to forestation across models. In particular, the value of minimum stomatal resistance (R_{min}) differs importantly between CLASS and NOAH (by a factor of 2 and 3 for needleleaf and grasses, respectively). But total stomatal conductance (inverse of stomatal resistance R) also depends on other components of the parametrization — the equation used to model the bulk effect of all the physical, chemical and biological processes implicated in plant transpiration. In second-generation land surface models such as CLASS and NOAH, R is assumed to take the empirical form:

$$R = R_{min} F_1 F_2 F_3 F_4$$

where F_i are parametrizations of the effects of solar radiation, vapor pressure deficit, air temperature, and soil moisture (see for instance equation 16 of Chen and Dudhia, 2001). Each of these F_i is itself a simplified model of a complex process comprising its own set of uncertain

parameters. Thus, minimum stomatal resistance is one but many of the parameters determining total stomatal resistance and its uncertainty.

And stomatal resistance is only one of the many uncertain land surface model parameters: albedo, LAI, root depth and roughness — to name the few listed in Table 2 — all vary between CLASS and NOAH by a similar factor. For instance, LAI and roughness differ by a factor of 3 and root depth by a factor of 4 between the NOAH and CRCM needleleaf forests. It is plausible, as the reviewer suggests, that the low minimal stomatal resistance in WRF-NOAH contributes to the increased latent heat fluxes and precipitation, but we could not afford the numerous sensitivity runs necessary to attribute the signal to one parameter or the other.

In summary, we agree with the reviewer's main point: uncertainty in the land surface model parameters may directly impact the forestation response across models, and we believe this is of concern not only for stomatal resistance (let alone minimum stomatal resistance) but also for the other land surface model parameters as well. However, the goal of this study is to test regional climate model responses to forestation in their operational configuration. The sensitivity tests required to fully address the reviewer's concern are thus outside the scope of this study. We nevertheless propose the following additional paragraph to the discussion section 6:

Section 6:

Also consistent with previous investigations is the importance of turbulent fluxes partitioning for the summertime response. We find that the ratio of latent heat fluxes to the total turbulent heat fluxes, or evaporative fraction, is inversely related to the surface temperature response. While we attempt to rationalize the partition seen in our simulations using the basic vegetation parameters such as leaf area index, roughness, albedo and root depth, a robust understanding of why a given model produces a given partition is cruelly lacking, and remains an outstanding issue (Pitman et al., 2009; de Noblet- Ducoudré et al., 2012). The large inter-model differences in the parameters of Table 2 — a small subset of the parameter list needed by the land surface models — reflects the wide uncertainty range associated with them. For instance, minimum stomatal resistance, LAI and root depth differ respectively by factors of 2, 3 and 4 between the NOAH and CLASS needleleaf categories. For instance, it is plausible that one (or a combination) of these parameters is responsible for the enhanced summertime latent heat fluxes in WRF. However, without several additional parameter sensitivity runs, it is not possible to rigorously attribute such a signal to vegetation parameters. In fact, even in the case of the two versions of the CRCM, which share the same land model and vegetation parameters, important differences in the turbulent fluxes partitioning are nevertheless seen. We conjecture that these differences may be attributed to updates in the physics parameterizations.

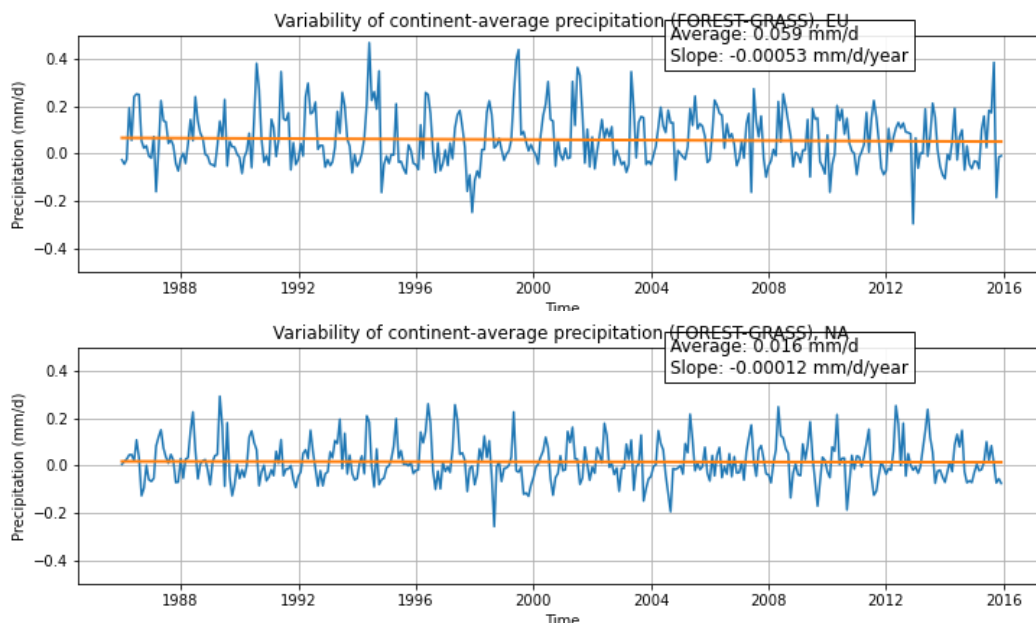
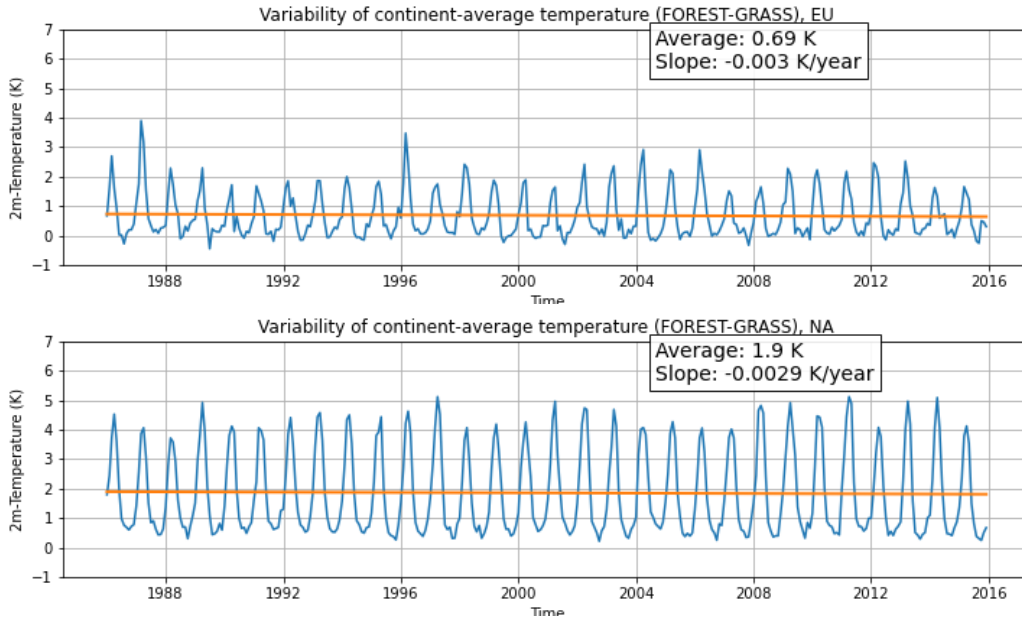
Related to the reviewer comment about the true value of needleleaf minimum stomatal resistance, we have searched the scientific literature for definite observational constraints, but couldn't find anything robust enough to be included here. If the reviewer knows of any such reference, for stomatal resistance or any other vegetation parameter, we would be happy to include it.

3. The simulations were analyzed over 1986-2015. The climate initial conditions are different among these 30 years. Does this affect the air temperature and rainfall response signal? What is the inter-annual variability in the air temperature and precipitation response to severe forestation?

From what we understand, the reviewer is asking whether the response to forestation evolves with the climate conditions over the period of analysis, 1986-2015. To answer this question, we plotted the monthly time series for near-surface temperature and precipitation averaged over land for CRCM5.

Short answer: the response to forestation in temperature and precipitation remains relatively similar over the period studied. There is inter-annual variability, but the trend is nearly flat for both precipitation and temperature on both continents.

Section 2.1

Following Davin et al. (2020), all simulations presented here were performed at 0.44◦ (∼ 50 km) horizontal resolution with lateral boundary conditions and sea-surface temperature driven by the 6-hourly ERA-Interim reanalysis (Dee et al., 2011). All three models were run over the North America CORDEX domain, and CRCM5 was run on the Europe CORDEX domain in addition (https://cordex.org). The simulations are analysed over 1986-2015, after a 7-year spin up allowing the models to adjust to land cover modifications. Since the forestation response was not found to change significantly over the analysis period, only climatologies are shown.

4. The winter biophysical climate response to severe forestation over North America has been repeatedly shown for CRCM5 in Fig. 2 and Fig. 5, and the same for summer climate response in Fig. 3 and Fig. 8. Is there a way to reduce this redundance?

It is true that maps of 2m-temperature, shortwave radiation and albedo in North America for CRCM5 appear twice in the paper. However, it seems to us like a more minor problem than the asymmetry caused by removing CRCM5 from these figures, plus the need of having to constantly flip through the pages of the paper. We thought this through but haven't found a solution that avoids redundancy without sacrificing clarity/symmetry/readability. If the reviewer has a specific suggestion we would happily consider.