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Climate of the Past Discussions

Interactive comment on "Radiative forcing by forest and subsequent feedbacks in the early Eocene climate" *by* U. Port et al.

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We thank the anonymous referee and Johan Liakka for their constructive comments which help to improve our paper. Below, we reply to the comments made by the referees point by point.

Referee 1:
...I did not know this feedback analysis method developed by Gregory, which, I suppose, has been developed in the framework of the global warming experiments. Indeed, the analysis was based on the first 150 years of the simulation (here the authors push the limit to 250 years) and no attempt is done to run the model up to 400 years. As a deep time modeler, it took me times before understanding why they

use such short simulations, the reason being tighten to the study of Gregory in which they analyzed global warming experiments. The IPCC climate runs are not defined to be representative of a globally warmer steady state climate as the atmospheric CO_2 concentration is constantly increasing through the human activities. Oils and coals production are supposed to stop in the next centuries, meaning that the CO_2 increase should stop in 200 years. During the Eocene, atmospheric CO_2 was probably higher than today but for thousands of years and at the same value.

The Gregory method (Gregory et al., 2004) allows to estimate the radiative forcing and the climate feedback parameter from any climate simulation in which the climate responds to an instantaneously changed and then constant(!) forcing. Hence, it is made for studies like ours which investigates the response of the climate system to sudden, but then constant, change in surface cover. The method is simply to regress the top of atmosphere radiative flux against the global average surface air temperature change. This method does not require special integrations or off-line estimates, such as for stratospheric adjustment, and it eliminates the need for double radiation calculations and computation of radiative fluxes at the tropopause to obtain the forcing as conventional methods require. Hence, the Gregory method is a very efficient method.

The Gregory method was not specifically designed for transient IPCC simulations, as it does not work in case of a gradually changing forcing. First applications were done to compute radiative forcing and feedback in climate change simulations triggered by constant forcing by doubling and quadrupling pre-industrial atmospheric CO_2 concentrations and by abruptly changing the solar constant to a new value. These simulations were relevant for the scenario simulations analysed in the Coupled Model Intercomparison Projects which were made use of in the IPCC assessment report. Like Referee 1, we are not aware of any study in which the Gregory method is applied to palaeo-climate simulations. Our study seems to be the first analysis of this kind.

Referee 1:
A major question concerns whether the tendencies seen in the experiment as run would have been maintained had the experiment been run to equilibrium, say for 2000 years. Having put their study in context, I would say that the way they simulate the Eocene is misleading. The authors should be more cautious and warn the reader of what they want to do.

The Gregory method has some limitations. It yields a good estimate of radiative forcing from the linear regression (Eq. 1 in the manuscript), if one does not consider too many years after the change in the forcing is effective. Gregory et al., 2004 took the first 90 years, we took the first 150 years out of our 400 years of simulation. Because of internal variability of the climate system, the scatter of values in the forcing – temperature response diagram increases as simulation progresses, and the estimate in radiative forcing and feedback parameter becomes less reliable.

The Gregory method allows to estimate the new equilibrium air temperature which the climate system should attain in response to the forcing (Eq. 2 in the manuscript). Li et al., 2012 find that the equilibrium near-surface warming in response to a doubling of atmospheric CO_2 concentration is underestimated by only 10% when using the Gregory method. This study highlights that the Gregory method provides a good estimate of the equilibrium temperature estimate. Unfortunately, the label in Tables 3 and 4 of the manuscript is misleading because we write 'equilibrium temperature change' instead of 'estimated equilibrium temperature change'. We will change this label in the revised version of our manuscript. Furthermore, we will add a paragraph on the limitations of the Gregory method to Section 3.1.

Referee 1:
The authors perform three experiments, a forest world, a bright desert world and a dark

desert world. They do the same three runs for a) modern conditions and b) Eocene conditions. Main changes are the prescribed ice-sheets, the atmospheric CO_2 level (from 1 to 2 times PAL) but I am not able to say what are the initial conditions? For the PI run, I suppose it is from a CTRL run with 280 ppm and modern vegetation distribution, but for the Eocene, what are the initial conditions, in terms of SST in the ocean? In terms of vegetation distribution? Please modify the text to give those details. Also, are the set of three experiments run from the SAME initial conditions? These details are important as they analyze transient and not equilibrated runs! Hence, the initial conditions are important. P. 1002, l. 17, it seems that the Eocene runs start from an equilibrated run with savannah? Any reference to an already published article?
Coupled Model Intercomparison Project

All Eocene simulations start from the same climate which is based on the 2500-year simulation by Heinemann et al., 2009. We repeated the Heinemann simulation with our model version starting from their equilibrium climate and using the same boundary conditions. By the end of the new simulations, atmosphere and ocean are in equilibrium with atmospheric CO_2 concentrations of 560 ppm, early Eocene orography and bathymetry, and continents homogeneously covered by savannah.

The pre-industrial simulations start from the 1000-year equilibrium control simulation described in Port et al., 2012 with dynamically interacting atmosphere, ocean, and vegetation and atmospheric CO_2 concentration of about 280 ppm, present-day orography, bathymetry as boundarCoupled Model Intercomparison Project y conditions. We will modify and extend our text to include this information. Figure C2 and C3 provide an overview over the initial climate (in terms of near-surface temperature and precipitation) in comparison to the climate at the end of the simulations. We will add these figures in an appendix to the manuscript.

Referee 1:
Table 3, how do you calculate the equilibrium temperature change?

The equilibrium temperature is estimated from the linear regression following Eq.. 2 in the manuscript according to Gregory's method (see reply above). We add a sentence to clarify this point.

Referee 1:
P.1008, Fig. 7, While the model generates a warming trend over the latitudes north of 15 N, large cooling trends are visible in the southern hemisphere when replacing a bright desert by a forest, can you comment on this unexpected result?

In Fig. 7, zonal mean temperature differences were corrected for global mean temperature. To obtain the differences in zonal-mean temperature between climates with completely forested and bared continents, the global mean temperature differences between these climates has to be added. Since the latter temperature differences amount to more than 4 K (see Table 3), the zonal-mean temperatures in the case of completely forested continents are always higher than those of continents with bright desert – as one would expect. We agree that Fig. 7 is misleading, and we now changed this figure (Fig. C1).

Referee 1:
P.1008 from line 18 to the end, the text is hard to follow, please give more details or remove this part. The sentence, line 24-25, is completely enigmatic.

We agree that our text is too short to be understandable. Basically, the last two paragraphs include an in-depth analysis of the difference in cloud feedbacks between early Eocene climate and pre-industrial climate. Therefore, we differentiated and analysed the feedbacks over continents and ocean, respectively. This separation

shows that cloud feedbacks over continents have almost the same strength in the early Eocene climate as in the pre-industrial climate. Over oceans, however, cloud feedbacks differ in sign indicating that any differences in the global cloud feedback can be attributed to the cloud feedback over the ocean. We will modify and extend this paragraph.

Referee 1:
At the end, we are left with another paragraph putting into question the hypothesis of a time invariant cloud feedback. And so what...I would say?

The last paragraph is, indeed, confusing in its current context. It points at a limitation of the Gregory method. We will skip this paragraph here, and we will add a few more words on the Gregory method earlier in the text (see reply above).

Referee 1:
Part 4.2 – I would suggest to the authors to take more time and to provide the reader with explanations explaining why forest cools the climate when compared to a dark desert. As it stands, no explanations are provided. I found that part really frustrating.

We apologise for any frustration. In principle, the case is rather simple: Relative to the dark desert continents, a forest cover affects the surface albedo only marginally. Hence in this case, the main radiative forcing is caused by changes in the cloud cover, i.e., Q_{SWcl} is the largest radiative forcing. Or in other words, forest cover increases the cloud cover leading to a higher planetary albedo and subsequent near-surface air cooling. We will modify this paragraph to make it comprehensible.

Referee 1:

l.13-15, this sentence is strange, I thought that we would see the real effect of the forest on the cloud cover and on the cloud radiative effect as now, there are no difference in terms of albedo. However, the authors affirm that changing from desert to forest does not impact the cloud over.
P.1010, L.18-26, again, I do not understand. It is related to the poorly written part 4.2 which leaves the reader with no explanations for the cooling effect of forest.

The confusion seems to arise, because we not only describe the effect of forest cover on dark soils, but also compare this effect with the effect of forest cover on bright soil. We will completely re-write this paragraph.

Comment by Johan Liakka
...in agreement with Referee 1, I find the temperature response over Antarctica in Fig. 7 to be the opposite to what one would expect. I say this because we published a paper last year in GRL where we examined the effect of forests on the Antarctic glaciation Liakka et al., 2014. Using the NCAR model, we found that forests have a warming effect on the Antarctic surface due to albedo effects. Maybe the authors could give some comments on this (unexpected) response in the revised version?

The seemingly unexpected response is due to the fact that Fig. 7 was misleading. As mentioned above, Fig. 7 dis not show zonal-mean near-surface air temperature differences, but the difference between zonal-mean temperature differences and the global mean temperature difference. To obtain the differences in zonal-mean temperature between climates with completely forested and bared continents, the global mean temperature difference between these climates had to be added. Since the latter amounts to more than 4K (see Table 3), the zonal-mean temperatures in the case of completely

forested continents are always higher than those of continents with bright desert – as one would expect. We redrew Fig. 7 (Fig. C1).

References

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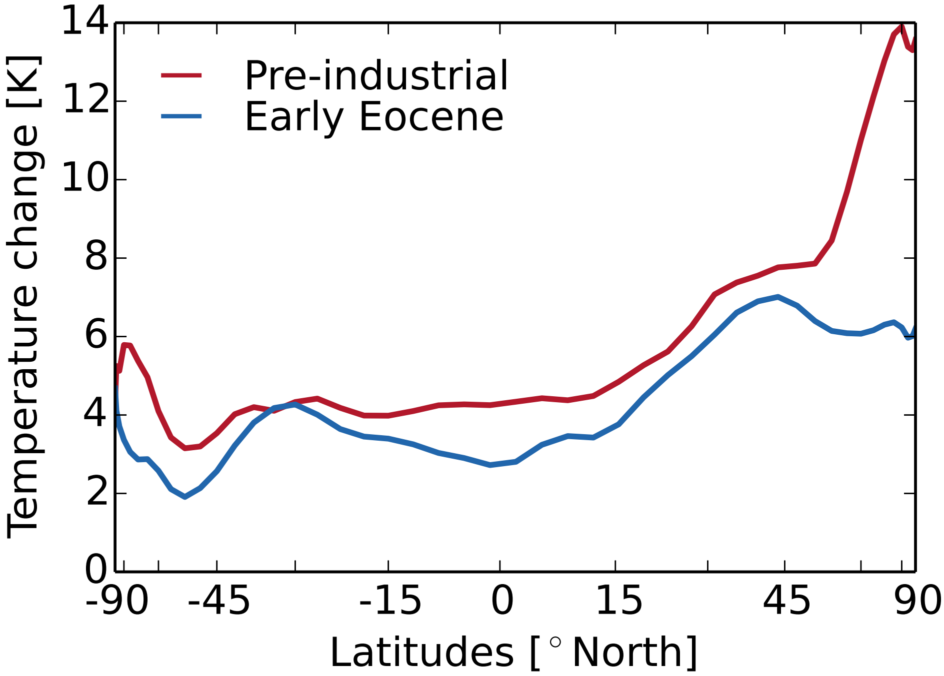

Fig. C1. Differences in zonal mean temperature between the forest world and the bright desert world. Blue line and red line refer to the early Eocene climate and the pre-industrial climate, respectively.

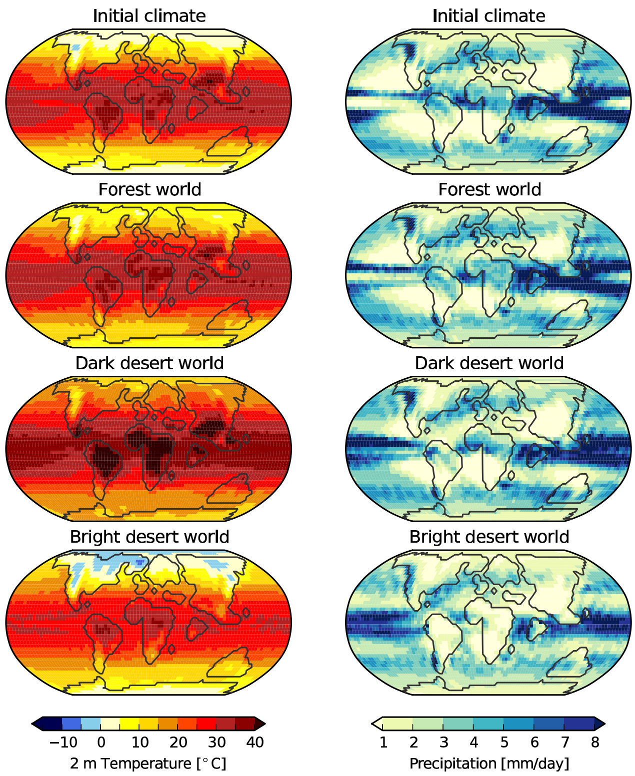

Fig. C2. Near-surface temperature and precipitation in the initial early Eocene climate and at the end of each early Eocene simulation. The average over 30 years is considered.

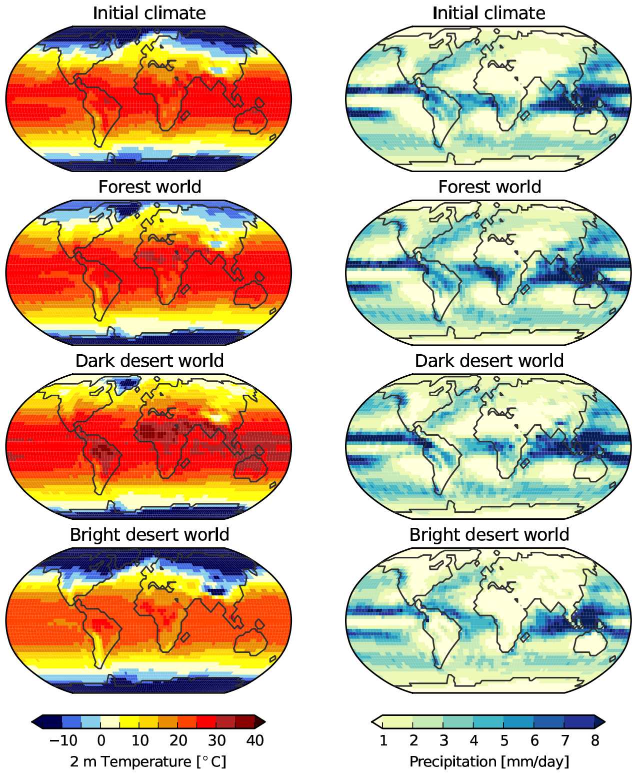

Fig. C3. Near-surface temperature and precipitation in the initial pre-industrial climate and at the end of each pre-industrial simulation. The average over 30 years is considered.