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Interactive comment on "Stability of the vegetation–atmosphere system in the early Eocene climate" *by* U. Port and M. Claussen

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We thank the referee for the constructive comments on our paper and the suggestions for improvement.

Referee 2
These results are not placed within any paleobotanical context so this is essentially a free-standing modelling result, which will probably be mainly of interest to others trying to prognose Eocene paleo-vegetation using predictive models.

Our study is indeed a modelling study in the first place, and we agree on adding some

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assessment of our result in view of palaeo-botanical evidence. In a paper submitted to Climate of the Past Discussion (Port et al., CPD, 11, 997-1029, 2015), we compared radiative forcing of forests and feedbacks triggered by changes in forests between interglacial, pre-industrial climate and a warm, nearly ice-free climate. For the latter, we used the early Eocene as an example. We found that feedbacks considerably differ between the interglacial and the ice-free climate. In this study, therefore, we aim to analyse whether the difference in feedbacks might lead to multiple states of the climate-vegetation system. The possibility of such multiple steady states has been investigated for pre-industrial climate, mid-Holocene climate, and glacial climate. But so far, no analysis has been done for a climate state that is much warmer, and nearly free of ice. To our knowledge, also the study of Shellito and Sloan (2006) did not specifically address the topic of multiple equilibria in an interactive vegetation climate-system.

Referee 2

(a) Is this the Early Eocene? [...] it appears these simulations are substantially too cold and with overly strong temperature gradient [...] for predictive vegetation modeling, the resulting vegetation types are a function of climate and CO_2. So to get a physical/biological consistency one must have the 'right' climate at the 'right' CO_2, or alternatively the study should span a wide combination of parameters. That is not performed here, which is a weakness in the approach.

We assume an atmospheric CO_2 concentration for our early Eocene simulations which is lower than in most other modelling studies but still in the range of estimates for the early Eocene (Beerling and Royer 2011). In fact, we take the same concentration that is specified in the simulations by Heinemann et al. (2009) which our study is based on and which is included in the model-data comparison by Lunt et al. (2012). The resulting modeled near-surface temperature matches proxy data in the tropics and the mid latitudes well, while high-latitude temperatures are slightly too cold in our simulations. In comparison to reconstructions by Huber and Caballero (2011) and Lunt et. al (2012), near-surface temperature/SST in the northern high latitudes is 4 to 8 K lower in our simulation. In the southern high latitudes, the simulation agrees fairly well with the reconstructions. Only the reconstructions by Sluijs et al. (2006) and Bijl et al. (2009) indicate much higher temperatures than in our simulation but, here, the warm bias in TEX_{86} reconstructions needs to be considered (see attached Figure 1).

Despite the cold bias in high-latitude temperatures, our simulations are suitable for our purpose because we aim to explore the stability of the vegetation-atmosphere system in a warm, almost ice-free climate rather than to simulate the early Eocene climate as realistic as possible. We added an evaluation of the simulated near-surface temperature to the companion paper (Port et. al 2015), and we will add a critical assessment on our simulated surface temperatures in the present study as well.

Referee 2

(b) Are these results similar to or different from other models or data? [...] Comparable model-predicted vegetation patterns have been simulated, but none of the relevant publications are discussed (Shellito and Sloan, 2006a,b - not cited ; Lopston et al., 2014 - not cited; Herold et al., 2014 - not cited). Nor are the various data-derived compilations and model boundary conditions compared against (such as Sewall et al., 200 - not cited; Utescher and Mosbrugger, 2007 - cited). So one is at a bit of a loss to ascertain whether the results here are even in the correct ball park. I believe they are, but that should be shown.

Our results are in the correct ball park in several aspects. We agree that a comparison of the simulated vegetation cover with vegetation reconstructions for the early Eocene period will have to be added. Hence in a revised version of the manuscript, we will discuss the attached Figure 2 in which we compare our simulated vegetation cover with the collection of Utescher and Mosbrugger (2007).

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(c) Very little effort is given in this paper to describing soil properties or spinup of JSBACH, but this could be a huge issue or nothing at all. For specificity, let me refer to Thum et. al 2011 in which various formulations of JSBACH are described. I am not sure which formulation is included in the study here, but the basic point for either model is that "The soil carbon pools of CBALANCE needed a run for 1080 years and Yasso07 for 3000 years to stabilize." [...] Given the fact that soil carbon pools will be completely different in equilibrium with different vegetation types coupled with the long equilibration time of soil carbon pools, the simulations currently shown may simply be still far from equilibrium...

We agree with the referee that we have to describe the spin-up procedure of our simulations more carefully. In the present study, we did not consider the dynamics of soil carbon. Hence, we did not have to consider the soil carbon pools of CBALANCE or YASSO which, indeed, would have required several thousand years of spin-up time. Instead, we prescribed a constant value of atmospheric CO_2 concentration, and we simulated only the dynamics of vegetation or living biomass. The time scales of the latter are of the order of decades. Hence, with a simulation time of 1000 years, we certainly reached an equilibrium.

How might this kind of difference in initial carbon pool affect the physical hydrological properties of the soil? What affects the soil permeability in JSBACH, are there long-memory processes in that (such as would be affected by different initializations?). What are the physical properties (normally based on soil texture) set in JSBACH? Is the soil texture and soil permeability the same in modern and Eocene simulations?

In the current version of our soil model, all physical parameters are prescribed. They do not change interactively with soil carbon content, and they are kept constant with time. For the sake of keeping our experimental set simple, we ignored any pedogenesis, and we used the same set of soil physical parameters for both pre-industrial and early Eocene climate.

(d) The study proposes that changes in Central Asia drive, through ocean-atmospheric feedbacks, distal vegetation responses, for example in North America. This is a reasonable hypothesis. The regions they have identified correspond to modern regions of high coupling coefficient (Bali and Collins, 2015 - not cited) and changes in diabatic heating and divergent circulation in the Indian Ocean are well established as links in the chain between all tropical circulations (for example the linkage between the Indian Ocean Dipole and ENSO). Such teleconnections are likely in the Eocene (Huber and Caballero, 2003 - not cited). One way of describing these results is that as one changes initial conditions a strong monsoon kicks in over Central Asia (figure 4) at the expense of a monsoon in the other main monsoon regions. Huber and Goldner (2012 - not cited) wrote extensively on evidence of a global Eocene monsoon system (in models and data) which is supported by subsequent data (Quan, et al. (2014)). So, the authors interpretation is a reasonable place to start, but they do not actually test this hypothesis with an appropriate model experiment.

Our hypothesis is consistent with earlier studies by Claussen (1997, 1998) and Kubatzki and Claussen (1998) in which a large-scale vegetation change in the tropics leads to multiple vegetation states independent of whether vegetation was changed in the region in which multi stability appears or globally. In these studies, a vegetation change in the tropics shifts the tropical atmospheric circulation which causes changes in regional subsidence in the tropic and adjacent sub-tropical areas. Ocean circulation and sea-surface temperatures were kept unchanged. Hence, multi stability was not caused by an ocean-atmospheric feedback but by vegetation-atmosphere feedbacks.

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We assume that this result also holds for our study. We find the idea of Referee 2 interesting, and we will submit simulations which differ in initial vegetation cover only in the Central Asian region.

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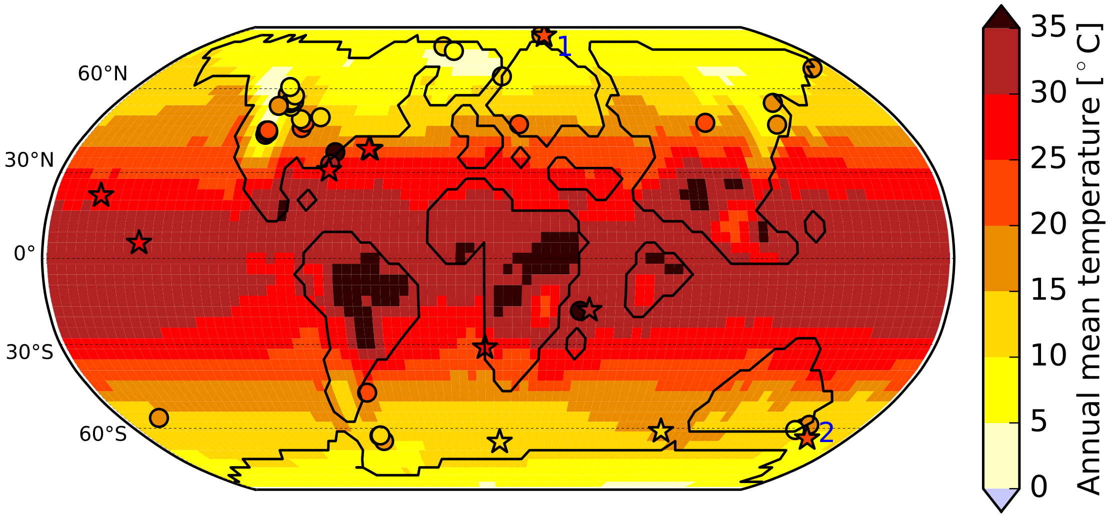

Fig. 1. Simulated annual mean 2-m temperature, reconstructed SST (stars), and reconstructed annual mean temperature (cycles). Numbers mark SST reconstructed by Sluijs et. al (2006) and Bijl et. al (2009).

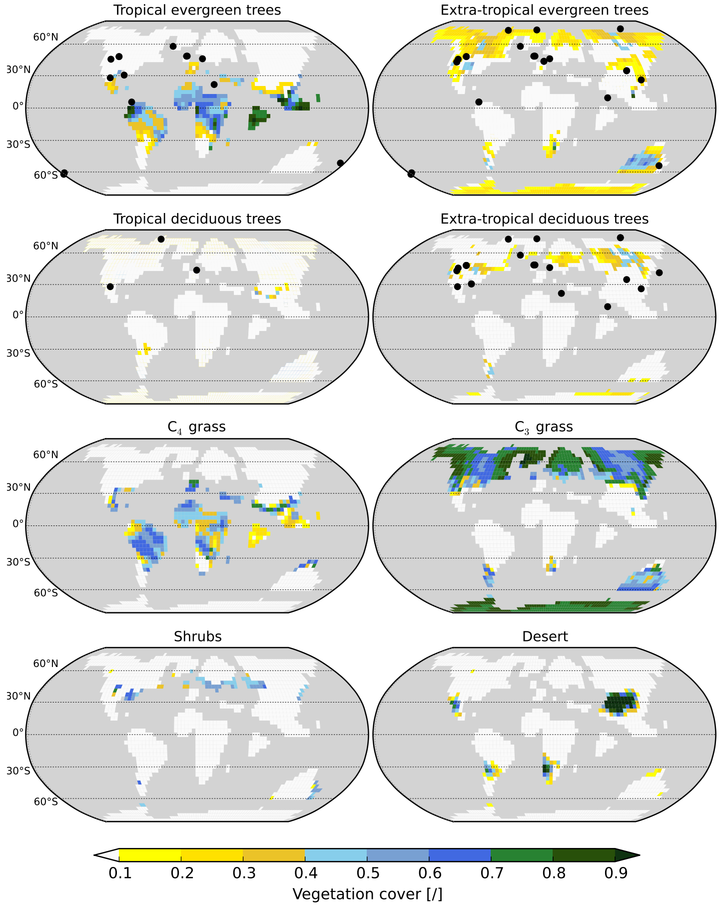

Fig. 2. Simulated vegetation cover in the simulation started from homogeneous bare soil and locations where the flora collection by Utescher and Mosbrugger (2007) suggests the existence of the respective PFT.

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