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Interactive Comment

Interactive comment on "Quantifying the effect of vegetation dynamics on the climate of the Last Glacial Maximum" *by* A. Jahn et al.

A. Jahn et al.

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We want to thank Marie-France Loutre for taking the time to review our paper and we will address her suggestions, questions, and criticism in the following.

We used factor separation for the two factors ice sheets and CO_2, and feedback analysis for vegetation. In the factor separation, the forcing is prescribed, while in the feedback analysis, the feedback is a factor of the state of the system and it changes in response to the forcing. Here we have chosen ice sheets and CO_2 as forcing/factor, because ice sheets and CO_2 are not captured interactively in the present version of CLIMBER. CLIMBER-2.3 simulates the interaction of atmosphere, ocean, vegetation, and we assume that atmosphere, ocean, and vegetation are close to equilibrium with the prescribed ice sheets and atmospheric CO_2 concentration.

In both factor separation and feedback analysis, the same terms, such as pure contribution and synergy, appear, but there are different assumptions behind them. In the factor separation, the term f_C reflects the response of the system to CO_2 forcing. In the feedback analysis, the term f_{CV} reflects the response of the system to the vegetation changes that occur as a reaction to the CO_2 forcing. The synergy term f_{CI} depicts the additional response of the system to applying both forcings, CO_2 and ice sheets, simultaneously. In our numerical experiments, this term appears to be very small on global average. The synergy term f_{CIV} shows the additional climate response due to the vegetation feedback to the simultaneously applied CO_2 and ice sheets forcing. Also this term appears to be much smaller than all pure contributions. We will include part of this explanation at the end of the current section 2.2.

Below are the comments to the respective points raised by M. Loutre:

1. The abstract in its present version is indeed misleading, and it will be modified. Furthermore, a table will be added in which all factor and feedback terms will be listed. It will become evident that the pure contribution of CO_2 forcing, the pure contribution of ice sheet forcing, and the vegetation feedback in response to CO_2 forcing only and in response to ice sheet forcing only add to nearly 100%. All synergy terms are small on global average.

2. Insolation was fixed at present-day conditions, because sensitivity studies showed that changing only the orbital parameters from present-day to LGM values caused a change of only -0.01°C (and also synergies with the orbital forcing factor were very small). This very small effect is due to very similar values of orbital parameters at 21 kyr BP and today, so that for our set of equilibrium experiments the changed orbital parameters did not have any significant influence. However, insolation changes are indirectly included in our study, since we prescribed ice sheets which build up as a results of the insolation forcing. Therefore,

orbital parameters were fixed at present-day conditions in order to calculate the pure contributions of changes in ice sheets and CO_2 as well as of vegetation feedbacks, without including the change in orbital parameters from present-day to LGM values in one of the factors without analyzing its effect independently.

To make this more clear, we will replace the sentence on page 6, line 3, starting with “Orbital parameters...” with “Sensitivity studies revealed that using LGM orbital parameters instead of present-day values did not cause any significant changes, due to the very similar values of the orbital parameters at the LGM and at present. Therefore we used present-day orbital parameters in all simulations for consistency.”.

3. All simulations were equilibrium experiments, which were integrated for 5000 years. Results shown are averages over the last 10 years of the simulations. This information will be included in the revised version of the paper. We will also reorganize section 2, following the suggestions of M. Loutre.

4. The strength of the Atlantic overturning circulation in direct comparison with its present-day strength might not have been stated very clearly in the text, but the cited figure of Ganopolski and Rahmstorf (2001, Fig 2) shows that the ocean circulation in the “cold” glacial circulation mode is indeed **weaker** than at present-day. Nevertheless, the northward heat transport and the intensity of the overturning circulation first increases due to the cooling caused by the ice sheets and the CO_2 individually, and only decreases when the climate changes caused by ice sheets and CO_2 are combined. The LGM simulation LGM_{CI} (as well as LGM_{CIV}) therefore has a weaker Atlantic overturning circulation than at present, in agreement with many other studies. We will make it more clear in the revised version that the strength of the Atlantic overturning circulation decreased in LGM_{CI} and LGM_{CIV} but increased in LGM_I and LGM_C relative to present-day.

5. The threshold of the ocean circulation could probably be passed by decreasing

only CO_2 very strongly or imposing more extensive ice sheets, as long as the resulting temperature change is large enough. However, within reasonable values for LGM atmospheric CO_2 concentrations and ice sheet extent, this threshold can not be passed by just CO_2 or ice sheet changes alone, at least not in CLIMBER-2. In other models, this might be possible due to larger sensitivities to changes in albedo or CO_2 (e.g., Kim (2004), where the ocean circulation decreases already when only CO_2 decreases to LGM values; however, it was not tested by Kim (2003) if also ice sheet changes alone could lead to this strong decrease in overturning in the Atlantic).

6. The global temperature change due to the vegetation feedback to the synergy between CO_2 and ice sheets is slightly negative ($-0.02°$C). As explained, the warming in the SH and the cooling over the North Atlantic is due to a further decrease in the overturning circulation and the northward heat transport, due to oceanic feedbacks to vegetation changes in northern Eurasia.

7. It probably should be mentioned again in the comparison with the results of Berger et al. (1996) that changing the orbital parameters did not cause significant changes in our equilibrium simulations, due to the very similar values of LGM and present-day orbital parameters. Therefore, the temperature change caused by f_I stays the same, even when insolation changes are included in this factor. Hence, we did not find a significant contribution of insolation changes to the simulated LGM climate in our sensitivity studies. This, however, was not meant to imply that insolation does not have any impact on the LGM climate in general. Rather, the effect of insolation changes in the years leading up to the LGM was included in the form of prescribed ice sheets based on reconstructions.

In regards to technical corrections:

Page 5, line 12–14: will be changed in the revised version

Page 5, line 24: The first sentence of 2.3 will be changed so that “LGM geography” will not be used.

Page 6, line 10: will be added in the revised version.

Page 8: f_{CI}^{V} is explained in the text on page 6, line 25-27.

Page 8, line 25: $\hat{f}_C$ was left over from an earlier version; it will be changed to f_C in the revised version.

Page 10, line 7: will be changed in the revised version.

Additional Reference:

Kim, S. J.: The effect of atmospheric CO_2 and ice sheet topography on LGM climate, Clim. Dyn., 22, 639–651, 2004.

Interactive comment on Climate of the Past Discussions, 1, 1, 2005.