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Climate of the Past Discussions

Interactive comment on "High resolution climate and vegetation simulations of the Mid-Pliocene, a model-data comparison over western Europe and the Mediterranean region" *by* A. Jost et al.

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We gratefully thank the referee A. Haywood for his constructive review of the manuscript. Below are the detailed answers to the comments, which will be fully considered in the revised manuscript.

We begin by discussing **our experimental design and modelling strategy**, which is the main concern of both reviewers.

1. High resolution over western Europe and the Mediterranean

There are number of reasons for running climate models at high resolution, the following among them:

i) to improve orographic resolution and hence, to reproduce precipitation pattern with a better accuracy, especially close to the main orographic features, although changes on a larger scale are also expected due to improvements in the simulation of the circulation.

In this respect, it is certainly crucial for mid-Pliocene climate modelling because of significant orographic changes, mainly due to Cenozoic tectonics. The most important differences in terms of elevation are noted in the Rockies Mountains and the Andes Cordillera, which were significantly lower in the mid-Pliocene compared with present day, and in a higher East African Rift System. Changes also involve Greenland and Antarctica, due to removal of continental ice. We agree that these regions would have been the most appropriate to test the importance of representing orography at high resolution, although the Alpine tectonics must also be responsible for elevation differences in the European and Mediterranean areas.

However the elevation of mountain belts is among the most difficult boundary conditions to reconstruct in deep-time paleoclimatology (Fluteau et al., 2001). There are only a few reliable measuremements, although the recent use of the "clumped-isotope" ($\triangle_{47}$) carbonate thermometer offers new possibilities of paleoelevation reconstruction (Ghosh et al., 2006). The mid-Pliocene relief is actually poorly known in detail and we do not have accurate data to constrain our model. The PRISM2 reconstruction is only a first order estimate of the mid-Pliocene orography derived from present day elevations and some inadequacies even arose since the PRISM2 reconstruction was published (Lunt et al., 2009). Therefore, in the absence of a realistic geological reconstruction of the mid-Pliocene relief, in particular in the study area, our simulation design could not account for the specific impact of regional orographic change. We admit that the sensitivity to the Alps and Pyrenees elevation would be worth studying.

We computed a high resolution mid-Pliocene topography anyway by adjusting the $2^\circ \times 2^\circ$ PRISM2 set of elevations to the finer grid, given the present spatial variability. The modern value from the high resolution control run over the finer grid is multiplied by the ratio between the modern value aggregated to the coarser grid and the PRISM2 value. This is done at each fine-grid point after the ratio has been first smoothed at low resolution and then simply refined on the high resolution grid. It results that our experimental design does account for the influence of a better resolved orography, even if the computed data set is similar to the control one over Europe and the Mediterranean.

ii) to improve the representation of dynamical and physical processes acting at small scales. Increasing horizontal resolution may not only contribute to improvements in the interaction of the dynamics and orography, but should also lead to a better simulation of storms passing over the North Atlantic (Jost et al., 2005). Indeed the European climate is significantly influenced by the perturbations of the large-scale atmospheric circulation (Kageyama et al., 1999) and the Mediterranean climate is strongly driven by local processes induced by its complex orography (Li et al., 2006). We could therefore expect improvements in the climate simulation, in particular in the redistribution of precipitation, due to a better resolved small scales dynamics.

iii) to investigate the impact of the resolution on the climate simulation, such as in Jost et al. (2005) for the Last Glacial Maximum (LGM). However additional comparison of the high resolution run to its low resolution counterpart would be required, which is actually beyond the scope of this paper. In the first comparison between two GCMs' simulations of the mid-Pliocene, Haywood et al. (2009) show that difference in horizontal resolution may explain discrepancies in the models' response in terms of precipitation rate and large-scale circulation via the differing representation of the main orographic features. We agree with the referee and his co-authors that this point would be worthwile to consider in future studies within Plio-MIP.

Besides, as the originality of our approach lies in the use of a fine-grid numerical model, with respect to previous modelling studies, we only considered models' results where the resolution is refined. It will not prevent us from discussing our simulations in the future at the global scale but we may wait until we run new simulations using the LMDz model according to the Plio-MIP design (Chandler et al., 2008; Haywood et al., 2009).

iv) to give more detailed climatic information, with a spatial scale more appropriate to compare with abundant local data in the study area. One of our objectives was indeed to draw a quantitative model – pollen data comparison.

In the end, the use of a finer resolution model, with a better description of both the orography and small scale dynamics, does not help to provide a simulated precipitation field in good agreement with the data, as it did for the LGM at the European scale (Jost et al., 2005). Thus the fact that the orography of the mid-Pliocene is not described properly (e.g., the weaker constraints on the elevation of the Alps and the Pyrenees) may be part of the explanation of this different behaviour.

May we also add that we chose to focus on western Europe and the Mediterranean simply because this region is of great interest, given its high vulnerability to future global climate change. The greater warmth experienced during the mid-Pliocene period is comparable to what is projected over this area.

2. Description of the LMDZ.3.3 and ORCHIDEE models

Additional information about the models will be mentioned in the experimental design section of the final version.

3. Climate-vegetation modelling

We perfectly agree with the referee that including vegetation as a dynamic boundary is the most appropriate modelling strategy to investigate mid-Pliocene climate-vegetation feedbacks and that running ORCHIDEE in dynamic mode would have improved the model-data comparison, as demonstrated by Haywood and Valdes (2006). They show that the implementation of a dynamic vegetation model in the GCM contributes to improve the mid-Pliocene biomes simulation, mainly in tropical regions. We opted for an asynchronous coupling of our global vegetation and climate models, as in Kageyama et al. (2005) or Sepulchre et al. (2007) for past climate simulations, because the fully coupled model was still in development at the time of running the experiments.

We also agree that specifying a PRISM2 vegetation or an estimate of Potential Natural Vegetation (PNV) as a starting point would have been more appropriate for an off-line vegetation experiment. However, their translation to combinations of ecological functioning categories used by land surface models may add uncertainty and bias due to a lack of coherence between land cover types and plant functional type (PFT) classification. We rather chose to use the same vegetation cover as in the control simulation, i.e., modern vegetation, although we are aware that climate-vegetation system could be sensitive to the initial distribution of vegetation (Claussen, 1994). As the vegetation impact on climate appeared to be small in the study area, i.e., the climatology given to ORCHIDEE is not very different from the one including changes made by the vegetation itself, we did not extend further the iterative process and therefore assumed that the largest vegetation change was obtained after the first iteration. We did not perform additional vegetation and climate simulations to ckeck this assumption to save calculation time, given the high resolution.

For what concerns the simulated mid-Pliocene vegetation cover, differences between PFT classification used by ORCHIDEE and PRISM2 land cover classes or biomes from pollen data or reconstructed from the Salzmann et al. (2008) data set prevent from comparing properly the above vegetation distributions, at best can we check their consistency (Sect. 4.3.1).

Here we compare instead the ORCHIDEE results for the middle Pliocene to an esti-

mate of PNV converted into PFT categories, created by Sterling and Ducharne (2008) (Fig. 1 and Table 1). During the mid-Pliocene, Europe is dominated by temperate broad-leaved (western Europe) or needle-leaved (eastern Europe) evergreen forest, with some tropical trees along the southern Atlantic and Mediterranean coasts. As compared to the mid-Pliocene vegetation, the PNV estimate shows an increase of bare soil in North Africa and a shift to temperate broad-leaved deciduous forest in Europe. This could stand for the mid-Pliocene warm temperate forest biome being replaced by temperate or cool temperate forests today, as suggested by Salzmann et al. (2008). If compared to a PNV simulated by ORCHIDEE using atmospheric forcings from a LMDz simulation for the modern period (M.-N. Woillez, personal communication), we could observe that the vegetation shift is actually manifested in an increase of the proportion of boreal PFTs to the detriment of the temperate PFTs in the PNV with respect to the mid-Pliocene simulated vegetation.

Finally it is expected that changes from a mid-Pliocene to a potential natural vegetation estimate would have a limited impact on the simulated climatology, and consequently on ORCHIDEE atmospheric forcings either.

4. About the atmospheric CO_2 concentration used in the mid-Pliocene simulations

See Author Comment in reply to Referee #2 Comment.

Minor comments

1. We gratefully thank H. J. Dowsett for his Short Comment providing the appropriate PRISM references, which will be included in the final version of our manuscript.

2. Middle Pliocene or Mid-Pliocene has been reworded to middle or mid-Pliocene, without capitalization.

3. We plan to shorten the abstract in a revised manuscript.

4. This statement is amended to “A large number of modelling studies (e.g., Chandler et al., 1994; Sloan et al., 1996; Haywood et al., 2000a; Haywood and Valdes, 2004; Jiang et al., 2005) suggests that global average temperatures were approximately 2 to 3°C greater than today”.

5. Done.

6. “Most excess precipitation” means “Enhanced precipitation”.

References

Fluteau F., Besse, J., Broutin J., and Ramstein, G.: The Late Permian climate. What can be inferred from climate modelling concerning Pangea scenarios and Hercynian range altitude?, Palaeogeogr. Palaeocl., 167, 39–71, 2001.

Ghosh, P., Garzione, C., Eiler, J.: Rapid Uplift of the Altiplano Revealed Through ^{13}C-^{18}O Bonds in Paleosol Carbonates, Science, 311, 511–515, 2006.

Sterling, S., and Ducharne, A.: Comprehensive data set of global land cover change for land surface model applications, Global Biogeochem. Cy., 22, GB3017, doi:10.1029/2007GB002959, 2008.

See other references in the Discussion Paper.

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Table 1. PFT classes from ORCHIDEE

	Bare soil
TropBE	Tropical broadleaf evergreen forest
TropBR	Tropical broadleaf raingreen forest
TempNE	Temperate needleleaf evergreen forest
TempBE	Temperate broadleaf evergreen forest
TempBS	Temperate broadleaf summergreen forest
BorNE	Boreal needleleaf evergreen forest
BorBS	Boreal broadleaf summergreen forest
BorNS	Boreal needleleaf summergreen forest
C3Gr	C3 grass
C4Gr	C4 grass
C3Crop	C3 crop
C4Crop	C4 crop

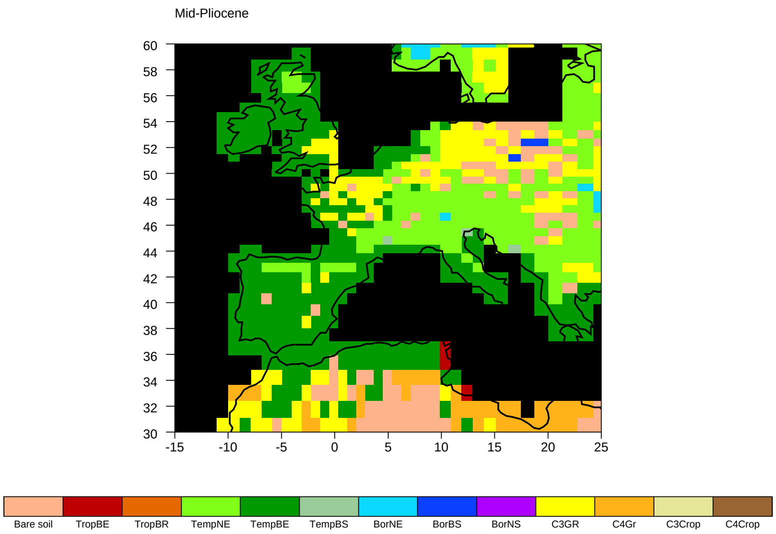

Fig. 1. Map of dominant PFT class for Europe and the Mediterranean, simulated by ORCHIDEE for the mid-Pliocene epoch.

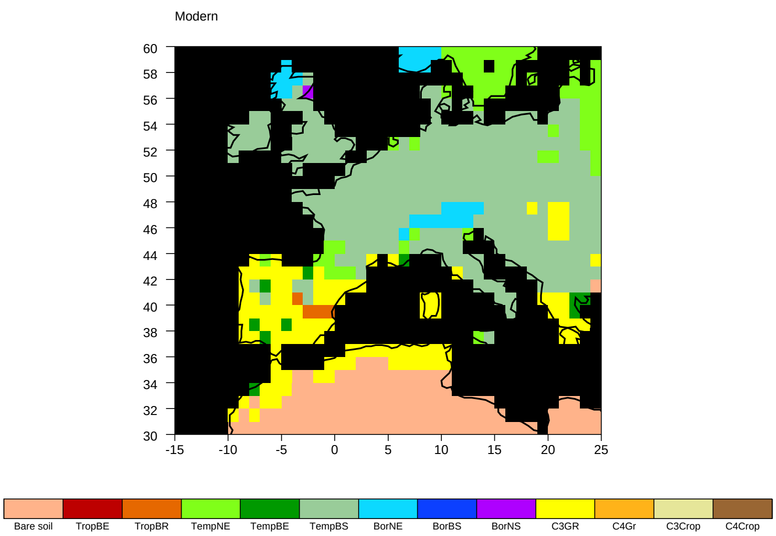

Fig. 2. Map of dominant PFT class for Europe and the Mediterranean, in a PNV estimate converted into PFT categories (Sterling and Ducharne, 2008).

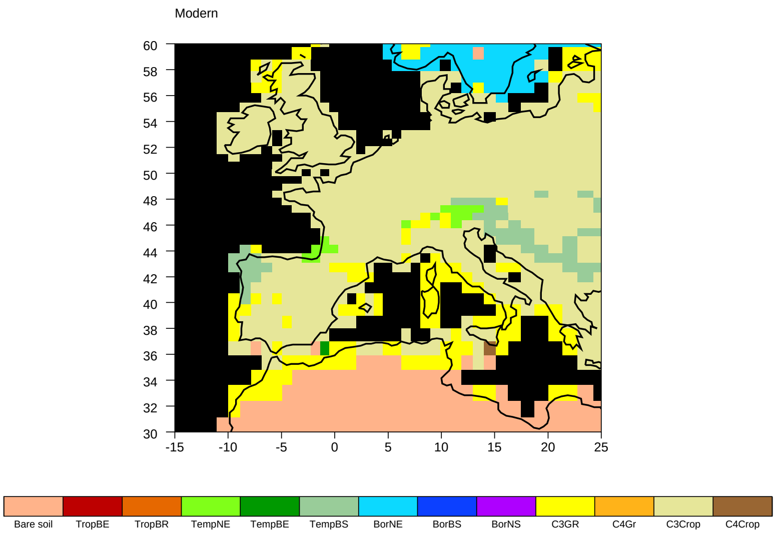

Fig. 3. Map of dominant PFT class for Europe and the Mediterranean, in the modern anthropogenic vegetation.