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Climate of the Past
Discussions

Interactive comment on "Evaluating the dominant components of warming in Pliocene climate simulations" *by* D. J. Hill et al.

Anonymous Referee #1

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General comments:

The authors analyze eight previously published mid-Pliocene warm period AO-GCM simulations using a simple one-dimensional energy balance model (EBM). Their objectives are 1) to evaluate the causes of the warm mid-Pliocene climate, and 2) to identify differences between the GCM simulations. I believe that both objectives are potentially interesting and within the scope of CP. For example, if the mid-Pliocene is to be used to estimate the sensitivity of the present climate to anthropogenic CO_2 emissions, it is crucial to understand how much of the reconstructed mid-Pliocene warming was caused by elevated atmospheric CO_2 concentrations, rather than by other AO-GCM boundary condition differences.

Unfortunately, the manuscript in its present form poorly motivates those two objectives.

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What are possible causes of the warm mid-Pliocene climate? Are boundary condition changes other than CO_2 expected to have a large impact? Or is the goal of this study mostly to compare the response of the different models to the pCO_2 increase?

The authors use the EBM to estimate which part of the Pliocene warming in the different GCM simulations is due to longwave emissivity differences (i.e. the combined effect of lapse rate, water vapour, and other greenhouse gas changes), due to albedo changes, due to implied meridional heat transport changes, and due to the changing shortwave and longwave effects of clouds. As far as I understand, the authors' main conclusions are that most of the warming in the tropics is caused by greenhouse gas increases, which in most models is enhanced by a positive shortwave cloud radiative effect, and that most of the warming at high latitudes is due to a reduction of the clear sky albedo. Since the authors stick to the simple application of the EBM method, and do not look further into the reasons behind the diagnosed changes and differences between the models, the conclusions drawn are not substantial, and their scientific relevance remains unclear.

Specific comments:

Abstract / page 1601, lines 19-21: "These simulations show that high latitude albedo feedbacks provide the most significant enhancements to Pliocene greenhouse warming." This conclusion is not clear to me. Does "greenhouse warming" refer to CO_2 alone? In that case, the conclusion is that the high latitude albedo feedback is even more important than the globally averaged water vapor feedback. I doubt that. If "greenhouse warming" is meant literally, and includes water vapor, then the term "feedback" is inappropriate, because the high-latitude albedo response might precede the water vapor response. Looking at Fig. 4, the high latitude clear sky albedo effect does indeed look like the main contributor to the overall warming, but it is difficult to estimate the global mean effect, given that higher latitude bands cover smaller areas. Maybe a table with the meridionally averaged EBM components would help here. Still, the EBM analysis, which, as far as I understand is the basis for this conclusion, does not allow to

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distinguish between the direct CO_2 effect and the water vapor or lapse rate feedbacks.

page 1604, lines 17-21 / Fig. 1c and f: To my eye, Figs. 1c and f mostly show a high relative variation for small δSAT; they do not illustrate that the northern mid-latitude and southern high-latitude warming is much more variable between the models. As far as I understand, one of the two main objectives of this study is to understand the warming differences between the PlioMIP simulations. I would like to see maps of the surface air temperature (or temperature changes) for all of the different simulations. I think that could help to identify outliers – for example, to identify what the reason for the large clear sky albedo effect at 40-60°N in MRI-CGCM2.3 is, or what the reason for the large variability in the Hudson Bay is (Fig. 3a in Haywood et al. 2013).

page 1606, lines 11-18 and page 1607, lines 1-12: It should be noted that the lapse rate effect of the topography ΔT_{topo} is fully captured by ΔT_{ϵ}. Also, even if the approximation for ΔT_{topo} was accurate, it is not accurate to equate $\Delta T_{\epsilon cs}$ to ΔT_{topo} plus $\Delta T_{gg\epsilon}$ (equation on page 1607, line 1), because the not-topography-related lapse rate effect on the emissivity difference is neglected. It may be an ok approximation, but that should be discussed. Moreover, I think it should be mentioned that the lapse rate effect captured by ΔT_{topo} is only one consequence of the topographic differences. Topographic differences can also effect the heat transport terms (stationary wave effects), the surface albedo (for example changed snow cover as a feedback to the lapse rate effect or circulation changes), and cloud cover.

page 1607, lines 15-16: "The overall structure of the energy balance components is largely the same between all the simulations." I think it would be good to actually describe and discuss this overall structure, i.e. the robust features, first, before going into the details for each model. I like the structure of Section 7. By contrast, I find it hard to filter out the robust features from Section 6. I would suggest to remove Section 6, and, where necessary, discuss model outliers or differences in the respective paragraphs of Section 7, or after Section 7. But this is clearly just a matter of taste.

Figures 2 and 4: When reading Section 6, I was mostly looking at Fig. 4, not at Fig. 2. I think Fig. 2 is not necessary, because all the information is already in Fig. 4, except for the total warming for each model, which could be added to Fig. 4. Also, Fig. 4 works better to identify robust causes of the warming, and to identify outliers.

page 1610, line 27: The cooling in MRI-CGCM at northern mid-latitudes due to clear sky albedo changes seems to be quite special, none of the other models reproduces it. I suspect that this one simulation leads to the higher ensemble mean Pliocene albedo shown in Figure 5 in Russia and the Canadian Northwest Territories. Maybe the vegetation-type translation led to a different background surface albedo in the MRI-CGCM simulation? Or is it a different snow cover?

Table 2 / “climate sensitivity”: Please specify how the climate sensitivity has been computed for the different models. Is it the long-term or transient climate sensitivity? How long were the simulations, and over which time periods were the temperatures averaged? The Pliocene warming for the models is compared to the climate sensitivities in the text, but no substantial conclusions are drawn from that comparison. Also, which time period is used for the EBM computations? Regarding the caption of Table 2, “Climate sensitivity is a general value for each model…”: This statement is somewhat misleading. Climate sensitivity is not a general property of a model, but it is climate-dependent; the feedbacks depend on the climate state.

page 1611, line 21/22: “There are some suggestions of a similar increase…” This was not so clear to me, maybe it can be rephrased, or omitted if it is not important. The range of the temperature response is also increasing, or the range of the water vapour response, or of both?

Figure 4 / CCSM: I was wondering what causes the comparatively small greenhouse gas emissivity difference in the CCSM simulations over Antarctica. Could it be that the clear sky albedo response leads to a comparatively small warming, and consequently to a smaller water vapor feedback? This could be tested by comparing the respective

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water vapor changes. Do topographic changes play a role in that area? Also, it seems that the largest clear sky albedo warming in the south in CCSM occurs around 60°S rather than around 70 or 80°S like in the other models. Could this be due to a colder control climate, with larger sea ice coverage in the southern hemisphere? Maybe the CCSM warming over Antarctica and the Arctic does not melt as much snow, because the control climate is too cold?

page 1611, line 29 – page 1612, line 2: “This is due to an increase in cloud cover resulting from a northward shift of the Inter-Tropical Convergence Zone.” That’s interesting. Has this been discussed before from a paleo-climate perspective? A reference would be helpful.

page 1612, lines 2-4: “In the high latitudes a significant increase in clouds leads to a significant cooling due to cloud albedo...” A plot of the cloud cover changes would be interesting. Is the cooling shortwave cloud effect really due to increased cloud cover, or is it due to the larger radiative effect of the clouds over a darker surface?

page 1612, lines 15-16: “...reduction of overall transport into the Arctic (Fig. 4e). This would be an expected result of polar amplification in the Arctic region under climate warming.” Please explain. It is expected that polar amplification under climate change leads to reduced heat transport into the Arctic? The heat transport effect seems to be largest at 70○N, and it is not clear to me whether this warms the Arctic ocean or land. The central Arctic ocean in contrast appears to experience a warming due to the heat transport changes.

page 1613, lines 17-23: How the North Atlantic and Kuroshio Current regions impact the "large uncertainties in the relative contributions of the different energy balance components" is an interesting question. However, although Fig. 3c in Haywood et al. (2013) does show a relatively large SST variance, its effect on the zonal mean surface air temperature in the respective latitude bands might be minor. According to Fig. 3a of Haywood et al. (2013), the variance in the Hudson Bay and over large parts of Eurasia seems to be important. Is the large variance over the Hudson Bay caused by different land-sea masks used in the models?

page 1614, lines 3-4: "Particularly strong warming in the high latitudes is driven by albedo feedbacks, especially from sea ice, ice sheets and vegetation." It has not been shown in the paper that sea ice, ice sheet, and vegetation changes are more important albedo feedbacks than for example snow or cloud cover changes. In fact, Fig. 5 indicates that vegetation changes in the Northwestern Territories and Russia may even cause a cooling.

page 1614, lines 4-5: "This is the region with the largest warming signal and also the largest uncertainties between the simulations. Therefore, improvements in the reconstruction of global ice cover and Arctic vegetation, along with improved data to evaluate the simulation of sea ice and high Arctic atmospheric and ocean temperatures, could significantly improve the simulations and allow much better constraints on total Pliocene warming." To use the model uncertainties to make more informed decisions about paleo-reconstructions is a great idea. I think that the "uncertainties" can be worked out more clearly. For example, the contributions from snow, sea ice, or vegetation could be estimated by looking at the respective model outputs. How do the sea ice concentrations differ, i.e. where are the paleo-sea-ice-reconstructions to be made, in order to eliminate possible model solutions? Over land, the snow cover could be compared. The effects of the snow cover could be separated from the effects of the prescribed vegetation changes by looking at the different background albedos without snow cover (if those fields are available, otherwise the comparison could be limited to snow-free areas, maybe just in summertime).

Technical corrections:

page 1602 line 15: I could not find ‘Hill et al. 2012’ in the reference list.

page 1603, line 16: “reconstruction represents the peak averaged warm climate” This sounds confusing, is it the peak or the averaged climate? If it is averaged, over which

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period?

Equations on page 1605 line 20, and page 1606 line 2: Please double check the signs. According to the equation on page 1606 line 2, H becomes positive if there is more incoming than outgoing radiation, so it would be a convergence, not a divergence, and the equation on line 20, page 1605 should read ...+H=...

Equation on page 1606 line 4: missing power of 1/4: $.../(\epsilon\sigma)^{1/4}$

page 1609, line 4: drop off. . .

page 1610, line 3: mid-latitudes

Figures 1, 2, and 4: the labels are too small

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