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Climate of the Past Discussions

Interactive comment on "Weakened atmospheric energy transport feedback in cold glacial climates" *by* I. Cvijanovic et al.

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Thank you for your comments and suggestions that helped improve the quality of our manuscript and also opened the space for an interesting discussion. We have tried to implement most of your points into our manuscript. Concerning your major point, we would like to discuss certain aspects in order to find a way of reconciling the two views.

Major comments:

My main concern with the manuscript is that the authors use anomalies in the northern hemisphere temperature gradient as a proxy for the ocean heat transport. It is somewhat arbitrary, and not obviously a good approximation. Even though the model setup only prescribes SST's and sea ice, the authors could

readily diagnose the implied ocean heat transport. For example, to get the implied cross-equatorial ocean heat transport just integrate and subtract the surface heat fluxes in the two hemispheres. Doing so would yield a correct feedback analysis; an ocean flux anomaly at a given latitude is partly compensated by an atmospheric flux anomaly with opposite sign. The feedback factor would be non-dimensional and can be more readily compared between PD and LGM.

We would like to clarify here that we did not attempt to use the anomalies in the NHTG as a proxy for the ocean heat transport. As you mention, it is not difficult to obtain the ocean heat transport anomalies from the surface fluxes. Yet, it was not our intention to use the ocean heat transport anomalies in our feedback analysis for the following reasons:

Firstly, we are dealing with atmosphere-only experiments where the SSTs are prescribed and there is no possibility of any ocean feedback. As the atmosphere is heated from below, the dynamics and transports are viewed as consequences of this heating/cooling and it is the surface temperatures that are causing the atmospheric changes. The question we are posing is this: Given the temperature forcing that is heating the atmosphere from below (SST forcing, in our case measured as the meridional temperature gradient) what is the resulting heat transport response? Our feedback analysis is therefore formulated as - given the change in TS (K) what is the change in atmospheric transport (W)? (The feedback factor has unit W/K). Usually in climate feedback analyses one would ask the question - given a change in TS (K) what is the change in TOA radiation (W/m2), which would not yield a non-dimensional feedback factor either (unit W/m2/K).

Secondly, atmospheric transport is dependent on the surface and TOA net fluxes (by definition this is a difference between the total and oceanic heat transport). Since the atmospheric heat transport is already calculated as the total minus the oceanic transport and there is nothing that the ocean can do to produce any feedback, we do not think that normalizing the atmospheric transport anomalies by the oceanic transport

anomalies will give a proper feedback analysis. Our aim was to make the normalization using the surface temperatures as the primary cause of change and not the surface fluxes (or, equivalently, the implied ocean heat transport).

Yoshimori and Broccoli (2008) found that the Hadley cell and cross-equatorial heat transport changes to various forcings are tightly linked to the interhemispheric temperature contrast in their mixed layer ocean model simulations (correlation coefficient equals -0.94). Furthermore, since our anomalies are in the NH we choose the NH temperature gradient as a common metric for all the experiments in the set. In light of those findings, we could discuss the use of the interhemispheric temperature contrast anomalies instead of the NHTG anomalies, but since the two are highly correlated this would not change our results significantly.

Choosing the prescribed SST configuration for our experiments enables us to study the atmosphere only response to the perturbation applied, but does not allow for ocean circulation or ocean surface feedbacks and therefore we argue that using the ocean heat transport anomalies instead of NHTG in the feedback analysis would not be adequate to answer questions about atmospheric heat transport feedback. We do agree that using the ocean heat transport anomalies would be the right approach in the case of a more complex experimental setup allowing for ocean feedbacks. In our ongoing work, in which we use the mixed layer ocean, we do apply such an analysis.

We hope that our comments help to reconcile the two views. We would be grateful to hear your further comments or ideas on the best way of fitting our approach into a more general picture that you have proposed. Your concern made us aware of the necessity of including these considerations into our manuscript and further elaboration on the choice of NHTG versus the ocean heat transport. Therefore, we have added the following paragraphs in Sections 1 and 4 (please note that NHTG has been renamed into Northern Hemisphere temperature difference - NHTD):

Section 2:

We consider the NHTD and not the alteration in the implied ocean heat transport in the following sensitivity analysis. This is due to the fact that the SSTs are prescribed in the simulations and there is no possibility of ocean transport feedback. As the atmosphere is heated from below, the dynamics and transports are here viewed as consequences of this heating or cooling, and it is the surface temperatures that are causing the atmospheric changes. Thus, given a surface temperature perturbation, which in this case is measured by the meridional temperature difference, we investigate the resulting atmospheric heat transport response. The normalization is therefore performed using the surface temperatures as the primary cause of change and not the surface fluxes or, equivalently, the implied ocean heat transport.

Section 4:

Choosing the prescribed SST configuration in our experiments enabled the study of the atmosphere only response to the applied perturbation, but did not allow for ocean feedbacks. Further work is required to evaluate the response when the interactions with the ocean surface are allowed. In this case, ocean heat transport anomalies should be used in the feedback analysis instead of NHTD.

Minor comments:

Page 1236, line 23, which surface feedbacks are meant here?

We have edited the following sentence to:

Although the role of the atmosphere is considered secondary in this regard, various atmospheric and surface feedbacks, such as clouds, albedo, atmospheric energy transport, can enhance or weaken the initial anomaly in the oceanic state.

Page 1242, Try explain the anti-correlated tail north of 60N. It should not be too difficult.

We have added the following sentence:

Northward of 60°N we see negative a DSE anomaly as a consequence of decreased temperature gradient between 60°N and area poleward of it.

Page 1243, line 25, replace flux with transport.

We have replaced it.

Page 1245, line 7, sensitivity to what?

We have rephrased the following sentence into:

Our study demonstrates enhanced mid-latitude atmospheric heat transport sensitivity to the imposed high latitude surface temperature perturbations under warm (interglacial) compared to cold (glacial) conditions.

Page 1246, line 20, '... and we therefore...' the jump to conclusion is a bit hard here, consider rephrasing.

We have rephrased the sentence:

Surface boundary conditions as seen by the atmosphere, i.e., topography, sea ice and SST, are quite different in PD and LGM, and the decreased LGM response we find is therefore a combination of all these factors.

Table 2, resort the experiments to be monotonic.

We have adjusted the table.

Figure 1 is very small. Figures 3, 6 and 8 could benefit from using colors, provided they do not cost extra. Generally, consider reducing the number of abbreviations, parentheses and the 'positive/negative – greater/weaker'-way of writing.

We have edited the Figure 1. Also we have replaced figures 1, 6, 7 and 8 with their colored versions and edited our style of writing where possible.

Interactive comment on Clim. Past Discuss., 7, 1235, 2011.