Response to Comments from Referee #2

We thank the referee for insightful and constructive comments. Below is our point-to-point reply to these comments (the reviewer's comments are in blue, and our responses are in black).

Review of the paper by Zhiping Tian et al. on Transient climate simulations of the Holocene (version 1) – experimental design and boundary conditions. The paper describes a model configuration for Holocene climate using CESM1.2.1. Compared to other PMIP participants it exploits a surprisingly high resolution of ~2° in the atmosphere and 1° in the ocean and does not employ any acceleration techniques. Using this setup the authors conducted some transient runs from 11.5ka until the pre-industrial era.

I like the paper in general but feel that the authors need to add more substantial material before it can be accepted by GMD. Hence I recommend the authors to resubmit the paper after significant revision.

1. The introduction leaves an impression that the authors know their topic and what they are doing. However, it consists of 3 parts and takes more than 30% of the paper. I see the authors need to make it more concise and keep only the relevant for the motivation parts.

   According to your suggestion, we have revised the introduction to make it more concise and keep only the relevant for the motivation parts. Please refer to the revised version for details.

2. I agree with the first reviewer that the model description lacks some details. Which parameterisations are used in the ocean and atmosphere, which coefficients etc. all this is not there. The presented setup does not really follow the PMIP4 protocol, doesn't it? I also wonder how the ocean was initialized for the spinup?

   Compared to previous model versions, the physical improvements in the oceanic component of POP2, used in both CESM1.2.1 and CCSM4, include a near-surface eddy flux parameterization, an abyssal tidally mixing parameterization, an overflow parameterization to represent the Denmark Strait, Faroe Bank Channel, Weddell Sea, and Ross Sea overflows, a submesoscale mixing scheme, vertically-varying thickness and isopycnal diffusivity coefficients, and modified and generally reduced horizontal viscosity coefficients as detailed in Danabasoglu et al. (2012) and Hurrell et al. (2013). The atmospheric component of CAM4 contains notable improvements in the deep convection parameterization, in which the calculation of Convective Available Potential Energy (CAPE) has been reformulated to include more realistic dilution effects through an explicit representation of entrainment, and sub-grid scale convective momentum transports have also been added. The CAM4 also contains improvements in the cloud fraction parameterization with a freeze-drying process contributing to a greater consistency between polar cloud fraction and water condensate properties, and in the radiation interface and computational scalability as detailed in Neale et al. (2010). The above details in the model description on the parameterizations and coefficients used in the ocean and atmosphere have been added in the revised manuscript accordingly (Lines 168–172 and 176–180).

Most of the presented setup for our all-forcing transient experiment follows the PMIP4 protocol for the transient deglaciation (21–0 ka) experiments, including the boundary conditions of astronomical parameters, trace gases, ice sheet and orography from 11.5 ka to the preindustrial period. The meltwater flux change is not considered here, which is also one of the three options in the PMIP4 last deglacial experiment protocol (Lines 278–279). Since our transient simulations start from the early Holocene at 11.5 ka, the spin-up experimental setup is different from that recommended for PMIP4 transient deglaciation experiments, the latter of which uses the last glacial maximum spinup (21 ka) or the transient orbit and trace gases spinup (26–21 ka). In particular, the initial ocean condition is taken from an archived 500-yr spinup from NCAR model case “b40.1850.track1.2deg.003”, a preindustrial control experiment performed by CCSM4 with 2° resolution in the atmosphere and 1° resolution in the ocean, which can be downloaded from the CCSM4 input data archive (https://svn-ccsm-inputdata.cgd.ucar.edu/trunk/inputdata/ccsm4_init/b40.1850.track1.2deg.003/0501-01-01/). We have added this information in the revised version (Lines 210–212 and 404–407).

3. line 295: Is it a standard practice in PMIP? I expect the effect is enorm!

There are three options for the freshwater fluxes provided for the PMIP4 transient deglaciation experiments: melt-uniform, melt-routed and no-melt (https://pmip4.lsce.ipsl.fr/doku.php/exp_design:degla). As one of the above options, the meltwater flux change is not considered in our Holocene transient simulations. Considering the high computational cost with the relatively high-resolution model (2° resolution in the atmosphere and 1° resolution in the ocean), the main purpose of running this set of Holocene transient simulations is to investigate the full- and single-forcing effects of several most important boundary conditions, including the orbital parameters, GHG concentrations, and ice sheets, on the Holocene climate evolution. The meltwater flux change, solar irradiance and volcanic forcing, land-use and vegetation changes, dust and aerosol effects, and stratospheric chemistry and dynamics are not fully considered here, all of which will have effects on the results as you pointed out. We have added the statements in the revised manuscript accordingly (Lines 278–279 and 391–394).

4. For a GMD paper on the model setup description it would be necessary to present the model performance, scalability and throughput for different model components distinguishing between IO, ocean and atmosphere costs etc.

Since this is a GMD paper on the model experiment description rather than on the model description, our main focus is on the model experimental setup and boundary conditions for the Holocene transient climate simulations, which is detailed in Section 3. Here we only give a very short model description in Section 2. Both us and the first reviewer think that there is no need to get more in depth, as the model is fully described in the cited literature (Lines 165–183). As you suggested before, more details in the model description on the parameterizations and coefficients used in the ocean and atmosphere have been added in the revised manuscript accordingly (Lines 168–172 and 176–180). Further information on the model performance, scalability, and throughput for different model components distinguishing between IO, ocean and atmosphere costs, etc., as you kindly mentioned above, are documented in the CCSM4/CESM1 special collection of the *Journal of Climate* (see http://journals.ametsoc.org/collection/CCSM4-CESM1), and additional model simulations for the past and present climates can be found, for instance, in Goldner et al. (2014), Song and Zhang (2018, 2019), and Park et al. (2019). We have added this information in the revised version (Lines 183–187).

5. My main comment is that the preliminary results are limited by one page and one plot which sounds a bit poor (10% of the paper). In the discussion of Fig.5 the authors try to interpret the drivers of Holocene climate GMST anomaly by using the additional 4 experiments where they sequentially turn off different boundary conditions. If I interpret Fig. 5 correctly I see that the anomalies in these 4 experiments do not sum to the reference experiment (HT-ALL) containing all boundary conditions. This points to the high level of nonlinearity in the system and reduces the confidence of the discussion in the results section.

In the revised manuscript, we have added more preliminary results about the spatial distribution and zonal average of annual and seasonal surface air temperature changes at 6 ka in the HT-ALL simulation, as well as their comparisons with the mid-Holocene changes in the 14 PMIP4 model simulations and their arithmetic mean. Section 4 now extends to more than two pages with the addition of one Table and two plots. Please refer to the revised Section 4 (Lines 299–343), Table 3, and Figures 6 and 7 for more details.

You are right that relative to the average for 1750–1850 CE (0.2–0.1 ka) of the full-forcing (HT-ALL) simulation, the annual GMST anomalies since 10 ka in the three single-forcing experiments (HT-ORB, HT-GHG, and HT-ICE) do not sum to the anomaly in the reference experiment (HT-ALL) containing all boundary conditions as seen from Fig. 5 or the following Fig. R1D, which points to a level of nonlinearity in the system. First of all, rather than sequentially turning off different boundary conditions, the three single-forcing experiments are forced by only one of the three boundary conditions (i.e., orbital parameters, atmospheric GHGs, and ice sheets), with the other two boundary conditions fixed at 11.5 ka (see Lines 282–287 and Table 2 for experimental setup) in this study. Second, this nonlinearity in the system revealed from our HT-11.5 ka transient simulations performed by CESM1.2.1 also exists in other transient simulations covering the whole Holocene performed by CCSM3, LOVECLIM, and FOMOUS as shown in Liu et al. (2014). As displayed in the following Fig. R1A–C, relative to the average values between 1.5 and 0.5 ka of the full-forcing simulation, the global annual mean temperature anomalies in the single-forcing experiments do not simply sum to the anomaly in the all-forcing experiment in CCSM3, LOVECLIM, and FOMOUS, which is particularly evident for the evolution since 10 ka. However, after simply summing the anomalies in the single-forcing experiments and then through some translations or parallel shifts, the gray curve in Fig. R1A–C (the “sum” of the single-forcing simulations) is overall comparable to the all-forcing simulation in the three models. This kind of summation, through some translations or parallel shifts, also reflects a level of nonlinearity in the system. Therefore, the nonlinearity in the system is not unique in our transient simulations performed by CESM1.2.1, but is commonly existed in other transient simulations performed by CCSM3, LOVECLIM, and FOMOUS, which will have some effects on the results and calls for further investigation in the future. We have added this point in the revised manuscript accordingly (Lines 355–359).

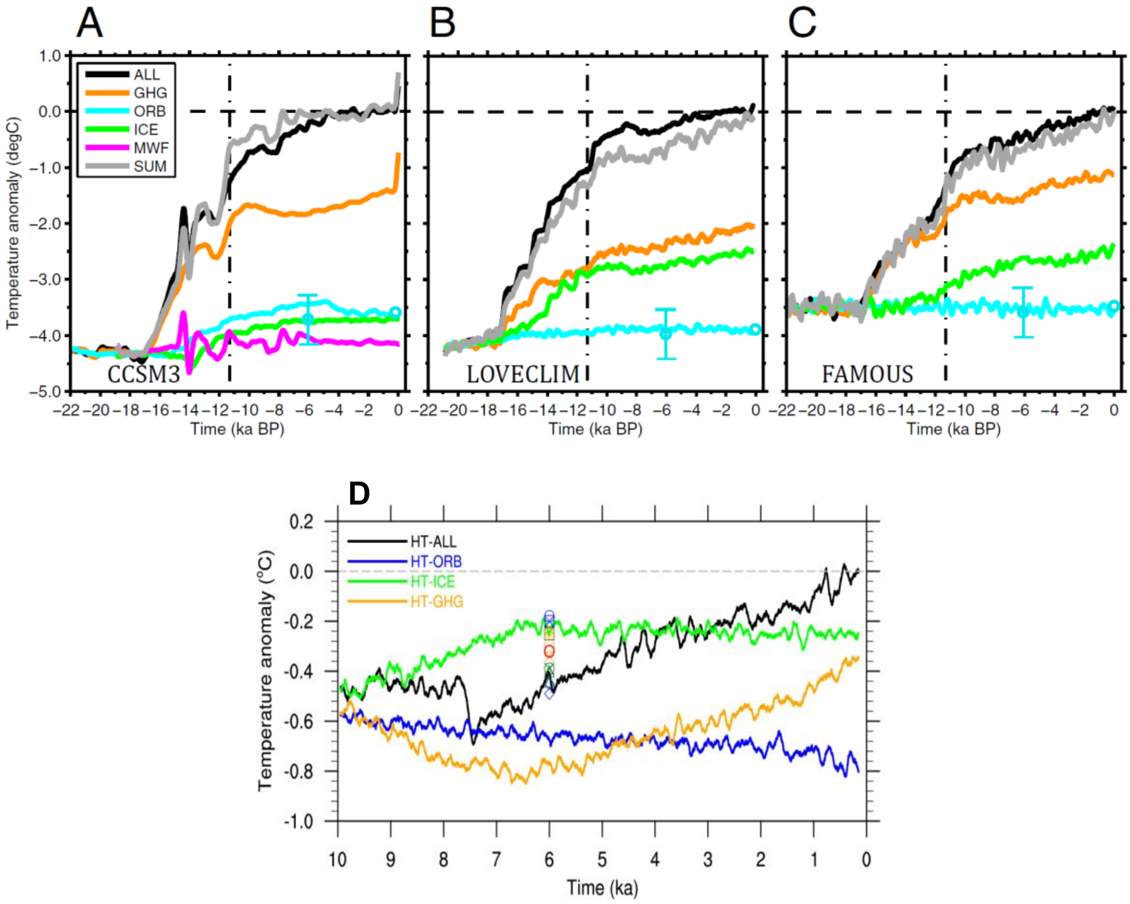

Figure R1: Global annual mean temperature anomaly under the all forcing (ALL, black) and the single forcings [GHG, orange; orbital, cyan; ICE, green; and meltwater flux, magenta (only in CCSM3)], as well as the sum of the single forcing simulations (SUM, gray) relative to the average values between 1.5 and 0.5 ka of the full-forcing simulation in (A) CCSM3, (B) LOVECLIM, and (C) FAMOUS as adopted from Liu et al. (2014). (D) Global annual mean temperature anomaly since 10 ka under the all-forcing (HT-ALL, black) and the single-forcing (HT-ORB, blue; HT-ICE, green; and HT-GHG, orange) simulations relative to the last 101 years (0.2–0.1 ka) of the full-forcing (HT-ALL) simulation by CESM1.2.1 from this study.

Reference:

Liu, Z., Zhu, J., Rosenthal, Y., Zhang, X., Otto-Bliesner, B. L., Timmermann, A., Smith, R. S., Lohmann, G., Zheng, W., and Timm, O. E.: The Holocene temperature conundrum, P. Natl. Acad. Sci., 111, E3501–E3505, doi:10.1073/pnas.1407229111, 2014.

6. I would like to see some key diagnostics from PMIP4 and how the HT-ALL experiment aligns with the other models. As an example one could look into Chris M. Brierley 2020 (https://doi.org/10.5194/cp-16-1847-2020, 2020) and do the comparison.

As you suggested, we have added some key diagnostics from PMIP4 and how the HT-ALL experiment aligns with the other models in the revised Section 4 with the additions of Table 3 and Figures 6 and 7. More specifically, following Brierley et al. (2020) as you mentioned, the spatial distribution of annual and seasonal (DJF and JJA mean) surface air temperature changes at 6 ka in the HT-ALL simulation is additionally displayed in Figure 6 and compared with the mid-Holocene changes in the arithmetic mean of the 14 PMIP4 models. Moreover, the global and zonal mean changes in annual and seasonal temperature changes at 6 ka averaged over the zonal bands of 60°–90°N, 30°–60°N, 0°–30°N, 30°S–0°, 60°–30°S, and 90°–60°S in the HT-ALL simulation are quantitatively compared with those in the 14 PMIP4 models and their arithmetic mean (Table 3 and Figure 7). As a whole, the above key diagnostics show that both at global and zonal mean scales, the annual and seasonal mean changes in surface air temperature at 6 ka in our HT-ALL simulation lie within the range of the 14 PMIP4 model results and are overall stronger than their arithmetic means. In particular, the annual and seasonal mean GMSTs simulated by CESM1.2.1 in the HT-ALL simulation are lower than those by CESM2 in the PMIP4 both for 6 ka and preindustrial simulations, but the mid-Holocene annual and DJF cooling magnitudes for the former are nearly double those of the latter, and the JJA cooling in the former is opposite to and four times the JJA warming in the latter. There are also some differences, mainly in magnitudes, for the zonal mean changes in annual and seasonal temperatures at 6 ka between the two versions of CESM. Please refer to the revised version for further details (Lines 299–343).

As a first step, this study provides the detailed model description, experimental design, boundary conditions, and some preliminary results for the new set of HT-11.5ka transient simulations. Further analyses on the simulation results including the mean climate evolution and abrupt climate changes over the Holocene both at global and regional scales, the underlying dynamic mechanisms, and comparisons with other transient simulations covering the Holocene and multi-proxy-based reconstructions, will be carried out by a series of follow-up studies.