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Final Technical Report

We have made significant progress in our proposed work in the last 4 years (3 years plus 1 year of no cost extension). In anticipation of the next phase of study, we have spent time on the abrupt changes since the last glacial maximum. First, we have performed further model-data comparison based on our baseline TRACE-21 simulation and made important progress towards the understanding of several major climate transitions. Second, we have made a significant effort in processing the model output of TRACE-21 and have put this output on a website for access by the community. Third, we have completed many additional sensitivity experiments. In addition, we have organized synthesis workshops to facilitate and promote transient model-data comparison for the international community. Finally, we have identified new areas of interest for Holocene climate changes.

I: TRACE-21 Analyses

With the analyses of TRACE-21 run and model-data comparison, we are making significant progress on several major climate issues, such as abrupt change of the African monsoon (Liu, 2010; Liu et al., 2010; Otto-Bliesner et al., 2013) and Asian monsoon (Liu et al, 2013), deglacial climate evolution and mechanisms (Liu et al., 2009; He, 2011; He et al., 2013, Williams et al., 2012; Veloz et al., 2012; Murray et al., 2012; Blois et al., 2013), abrupt climate changes and the AMOC (Cheng et al., 2010, 2011a,b; 2012, 2013; Hu et al., 2012), climate-ice sheet interaction (Marcott et al., 2011; Carlson et al., 2012), climate sensitivity and isotope modeling in the Arctic (Liu et al., 2012) and monsoon region (Liu et al., 2013). We designed a new indicator for thermohaline stability for the equilibrium (Liu and Liu, 2013) and evolving AMOC (Liu W. et al., 2013). We have also participated in a comprehensive synthesis of global climate evolution and its comparison with the model (Clark et al., 2012; Shakun et al., 2012). We also contributed to the education of general climate changes in the past (Liu, 2011; Liu and Braconnot. 2012). Our products include 1 on Science and 2 on Nature, and 3 on PNAS. Here, we will highlight two examples.

1. Synthesis of global climate evolution during the last deglaciation (Clark et al., 2012)

Deciphering the evolution of the global climate from the end of the Last Glacial Maximum ~19ka to the early Holocene 11ka presents an outstanding opportunity for understanding the transient response of Earth's climate system to external forcings and internal variability. We are participating in a major effort by the paleoclimate research community to characterize these changes with a synthesis of well-dated, high-resolution records of the deep and intermediate ocean as well as surface climate. The synthesis is also compared with the TRACE-21 simulation. This synthesis indicates that the superposition of two orthogonal modes explains much of the variability in regional and global climate during the last deglaciation. One mode represents the effect of CO_2 forcing while the other represents the meltwater forcing. The model-data comparison also suggests that CCSM3 is able to capture these two major features of the global deglacial evolution.

2. Younger Dryas Cooling and the Greenland Climate Response to CO_2 (Liu et al, 2012)

Greenland ice-core $\delta^{18}O$-temperature reconstructions suggest a dramatic cooling during the Younger Dryas (YD; 12-9-11.7 ka), with temperatures being as cold as the earlier Oldest Dryas (OD; 18.0-14.6 ka) despite an ~50 ppm rise in atmospheric CO_2. Such YD cooling implies a muted Greenland climate response to atmospheric CO_2, contrary to physical predictions of an enhanced high-latitude response to future increases in CO_2. Here we show that North Atlantic sea surface temperature (SST) reconstructions as well as transient climate model simulations suggest that the YD over Greenland should be substantially warmer than the OD by ~5^{o}C in response to increased atmospheric CO_2. Additional experiments with an isotope-enabled model suggest that the apparent YD temperature reconstruction derived from the ice-core $\delta^{18}O$ record is likely an artifact of an altered temperature-$\delta^{18}O$ relationship due to changing deglacial atmospheric circulation. Our results thus suggest that Greenland climate was warmer during the YD relative to the OD in response to rising atmospheric CO_2, consistent with SST reconstructions and physical predictions, and has a sensitivity approximately twice that found in climate models for current climate due to an enhanced albedo feedback during the last deglaciation.

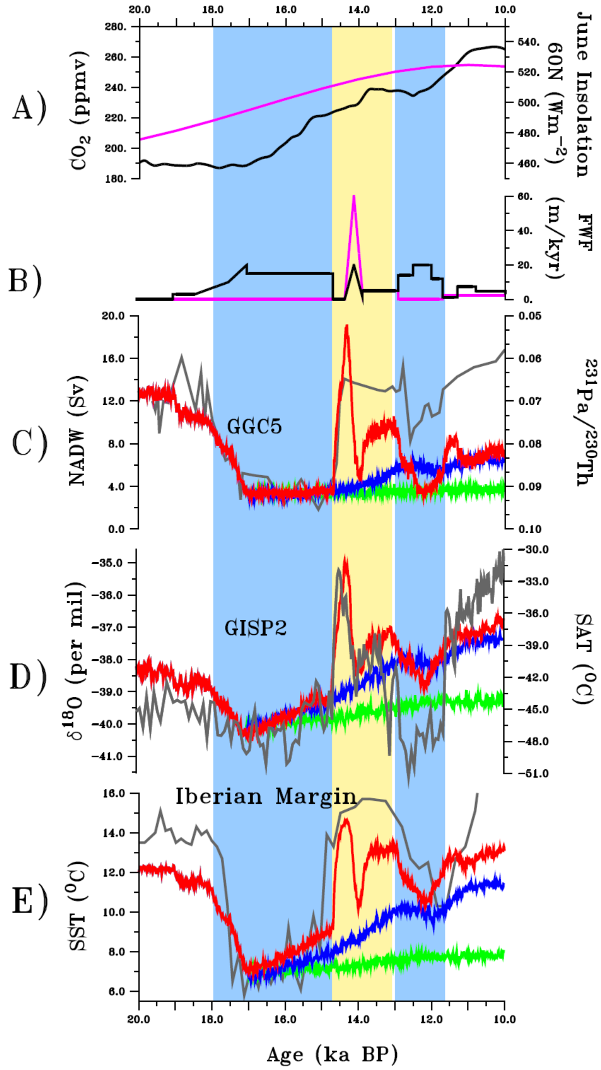

Fig. 1: Model forcings: (a) 60 °N June insolation (purple) and atmospheric CO_2 concentration (black), (b) meltwater fluxes into the North Atlantic (black) and Southern Ocean (purple). (c) AMOC for the model (red) and reconstructed (grey). (d) GISP2 $\delta^{18}O$ and surface temperature reconstruction (grey) and model (red; model offset by -3 °C), and isoCAM3 precipitation $\delta^{18}O_p$ (stars) (PI plotted at ~10 ka (Method 2)). (e) Iberian Margin SST (gray) (Fig. 2) and model (red). The CO_2 (blue) and orbital forcing (green) sensitivity experiments are also shown. All model variables are decadal means.

II: TRACE-21 Data Management

To benefit the entire paleoclimate community worldwide, we have made a significant effort to process the model output and post the data online. This work is much more difficult than in the past with time slice experiments, simply because of the volume of data. A single 2-D variable in monthly data is over 100 GB in size, and the entire dataset is over 11 TBs. For a data set of 100 GB, even ftp downloading becomes problematic for some users who are not accustomed to large model data sets. Furthermore, different users have different requirements. To maximize the benefit of the model output and minimize the technical effort of the users, we designed four tiers of data, as listed in the table below.

The decadal mean data (Tier I) was made available first. The monthly data, however, takes substantial time to process, and so is being released in two tiers: Tier II for the entire simulation but only a few key variables, while Tier IV for all variables but only for a few time slices. We have already had over 30 requests, for which we have also provided consulting on the data access and analysis.

Name	Resolution	Duration	Variables	Status
Tier I	Decadal mean	21ka—0ka	All variables (annual mean) Atmos. variables (seasonal mean: DJF,MAM,JJA,SON)	ready
Tier II	Monthly mean	21ka—0ka	Sfc temp, precip, winds, SST, vegetation, total about two dozens of variables	Atmosphere ready Other variables soon
Tier III	Time slice	20ka (LGM), 13ka (PreYD), 10ka (early Hol), 5ka (mid-Hol)	Restarts, Forcing files and boundary conditions	ready
Tier IV	Monthly mean	Selected 100 years (for regional modeling)	All variables	soon

The datasets are now on public website.
Tier I Server: ftp://pike.aos.wisc.edu/TraCE/TierI_decadal/
Tier II Server: ftp://pike.aos.wisc.edu
Tier III Server: ftp://pike.aos.wisc.edu/TraCE/TierIII_restart/

CCSM instruction on post processing model output
http://www.cesm.ucar.edu/models/ccsm3.0/ccsm/doc/UsersGuide/UsersGuide/node12.html
http://ccrlab21.aos.wisc.edu/~fenghe/PostProcessing/node12.html

III: Sensitivity Experiments

We have also continued with more sensitivity experiments. We have finished two Holocene experiments to test the effect of post-YD meltwater forcing and the role of Bering Strait. We will analyze these two runs in depth to understand the abrupt climate changes during the Holocene.
We have also performed CO_2 sensitivity experiments for several additional time periods. We have a new initiative for time-slice water isotope simulations using the iso-CAM3. We are also performing long simulations testing the hysteresis of the AMOC. We further completed a set of single forcing runs for the last 21000 years, for CO2 forcing alone, orbital forcing alone, meltwater forcing alone and ice sheet forcing alone. All these sensitivity experiments will help us further understand the mechanism of climate change and abrupt changes. These simulations are currently being analyzed.

IV: Future Work

We have several major tasks for the future. First, we will continue to expand our model-data comparison on many regional abrupt climate changes with our collaborators. Second, we will analyze the sensitivity experiments to isolate the roles of individual forcings: CO_2, ice sheet, meltwater and orbital forcing. Third, we are analyze single forcing runs in coordination with the major TRACE run to understand the mechanism of climate changes. Fourth, we identified a systematic mismatch of Holocene global temperature change between our model (and other models) and the new reconstruction (Marcott et al., Science, in press). We will further explore the cause of this mismatch and its implications to both models and data. Finally, we are also in the process of implementing water isotopes into the next generation of CESM.

Publication

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