Supplementary information to “A global glacial ocean state estimate constrained by upper ocean temperature proxies”

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Figure 1: Control changes derived for the diapycnal diffusivity coefficient $\kappa_d$ in GLACIAL in units of the prior control adjustment uncertainty, $10^{-4}$ m$^2$s$^{-1}$ (Table 1).
Figure 2: Control changes derived for the eddy bolus velocity coefficient $\kappa_{GM}$ in GLACIAL in units of the prior control adjustment uncertainty, 500 m$^2$s$^{-1}$ (Table 1).
Figure 3: Control changes derived for the isopycnal diffusivity coefficient $\kappa_\sigma$ in GLACIAL in units of the prior control adjustment uncertainty, 500 m$^2$s$^{-1}$ (Table 1).
Figure 4: Control changes derived for initial potential temperature in GLACIAL in units of the prior control adjustment uncertainty, $3^\circ$ C (Table 1).
Figure 5: Control changes derived for initial salinity in GLACIAL in units of the prior control adjustment uncertainty, $1 \text{ g kg}^{-1}$ (Table 1).
Figure 6: Annual mean salt fluxes due to brine rejection by sea ice formation in MODERN (top), PRIOR (middle), and GLACIAL (bottom). The total annual area-weighted Southern Hemisphere salt fluxes into the ocean are $1.3 \times 10^7$, $2.3 \times 10^7$, and $2.1 \times 10^7$ kgs$^{-1}$, respectively.
Figure 7: Time series of the evolution of surface and abyssal properties in MODERN, PRIOR, and GLACIAL. Drifts in surface temperatures (top) and salinity (middle) are summarized as the area-weighted root mean square difference of centennial-average values from time mean values over the first 100 years of simulation. Surface drifts are larger for MODERN and PRIOR than for GLACIAL. Changes in maxima of the Atlantic Meridional Overturning circulation streamfunction in the simulation are nonmonotonic (MODERN, GLACIAL) and large relative to mean values (PRIOR) over the first 1000 years of simulations, but show asymptotic behavior after several thousand years.
Figure 8: Final misfits in the sensitivity state estimate GLACIAL_s computed without globally uniform temperature adjustments. Lines show histograms of model-data misfits for annual, JFM, and JAS values normalized by observational uncertainty at adjoint iterations 0 and 6; the grey area shows the Gaussian distribution that is the target distribution of misfits. Although the spread of model-data misfit is similar to the target at iteration 6, an overall model cold bias persists.
Figure 9: Sea ice thickness in GLACIAL_s (colors) and 15% concentration isopleths (contours) in September (left) and March (right) for MODERN (gray) and GLACIAL_s (black).
Figure 10: Atlantic zonal mean potential temperature (left) and salinity (right) in GLACIAL (top) and GLACIAL_s (bottom).

Figure 11: Atlantic (left) and global (right) zonal mean streamfunctions in GLACIAL (top) and GLACIAL_s (bottom). Contours denote density in kg/m³ minus a reference value of 1000 kg/m³.
Figure 12: Comparison between LGM minus modern SST temperature anomalies computed as GLACIAL-MODERN (left) and GLACIAL_s-MODERN to illustrate the effects of global mean surface air temperature adjustments. Panels show the values in the uppermost model grid box (centered on 5 m water depth) averaged over July-August-September (top), January-February-March (middle), and the annual mean (bottom).