Supplementary Information for the article:

Ocean-driven millennial-scale variability of the Eurasian Ice Sheet during the Last Glacial Period simulated with a hybrid ice-sheet-shelf model

1. On the sensitivity to the ocean heat flux coefficient

As advanced in the main text, in order to investigate the sensitivity of the results to the model parameters, eight additional OCN simulations, both for the surface and the subsurface, have been carried out with different **κ** parameters between 1 and 10 m/a/K, i.e., bracketing our standard case of **κ** = 5 m/a/K, both for the OCNsrf and the OCNsub cases.

This choice reflects the inferences based on measurements made on Antarctic ice shelves (Rignot and Jacobs, 2002)

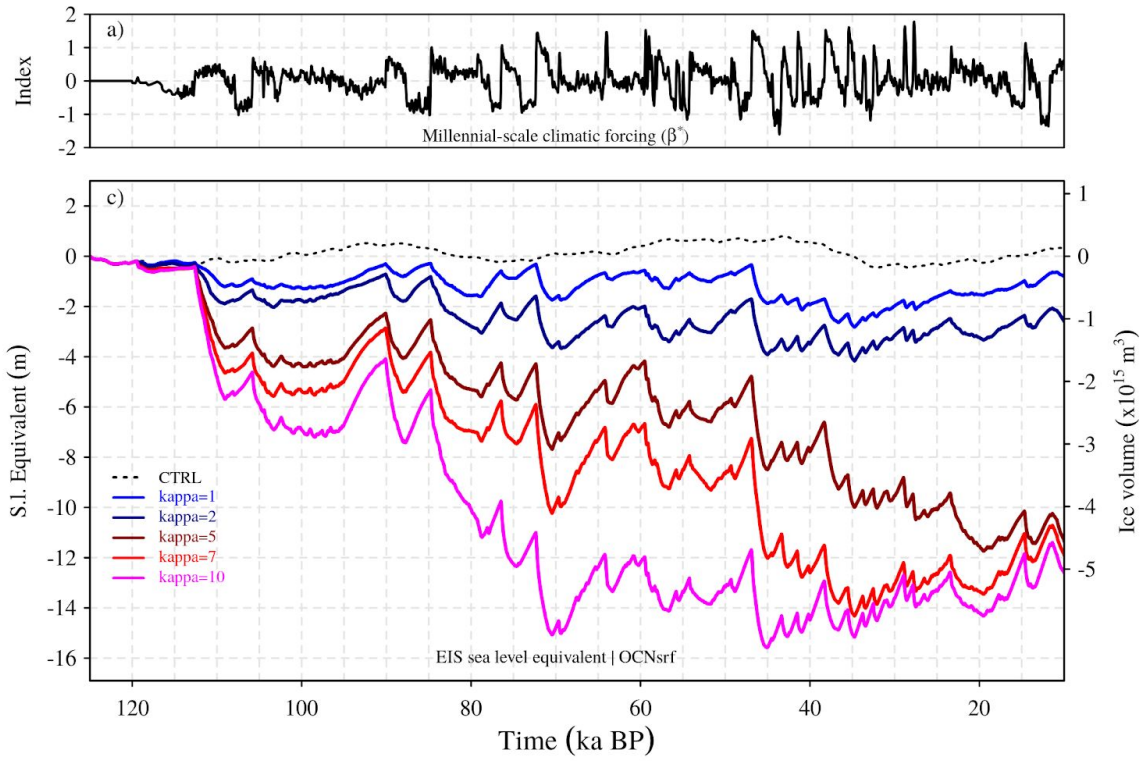

Figure S1 | Volume time series of the EIS for different values of the ocean heat flux coefficient corresponding to the OCNsrf forcing.

A robust response of the EIS is found, with a more reactive EIS response for increasing **κ** values, as shown in Figures S1 and S2.

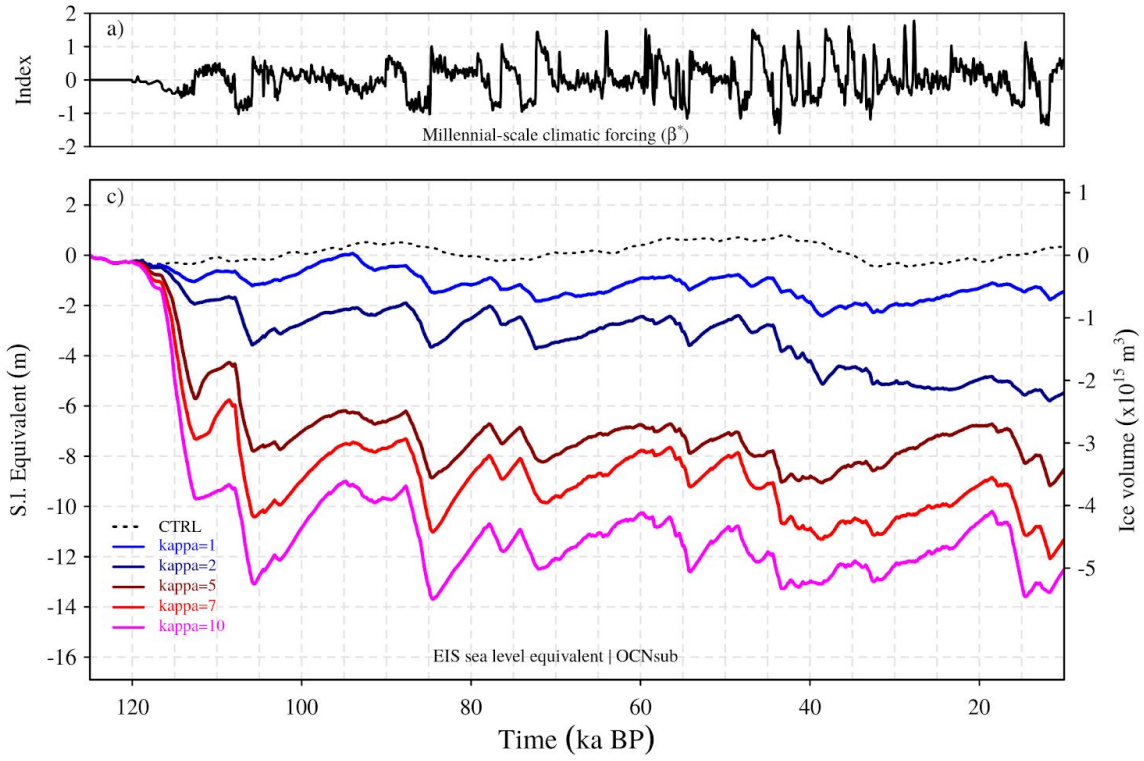

Figure S2 | Volume time series of the EIS for different values of the ocean heat flux coefficient corresponding to the OCNsub forcing.

2. On the sensitivity to the atmospheric forcing

To assess the uncertainty associated with the PDD approach and the response of the ice sheet to different oceanic sensitivities in terms of its dynamics, we performed a new ensemble of simulations.

We first explored the uncertainty of the PDD model by changing the value of its parameters. The simulations shown in the main text correspond to the following values of the PDD model:
σ = 5 K, f_PDD_ice = 0.008 mwe/PDD and f_PDD_snow: 0.003 mwe/PDD

We have also explored the sensitivity of our ice sheet model to the following range of values of these parameters:
σ: 4,5,6 K
f_PDD_snow: 0.0015, 0.003, 0.006 mwe/PDD
f_PDD_ice: 0.004, 0.008,0.016 mwe/PDD

Therefore, the sensitivity of our results to the values of the atmospheric mass balance model has also been explored in 91 additional simulations that are illustrated in Fig S3.

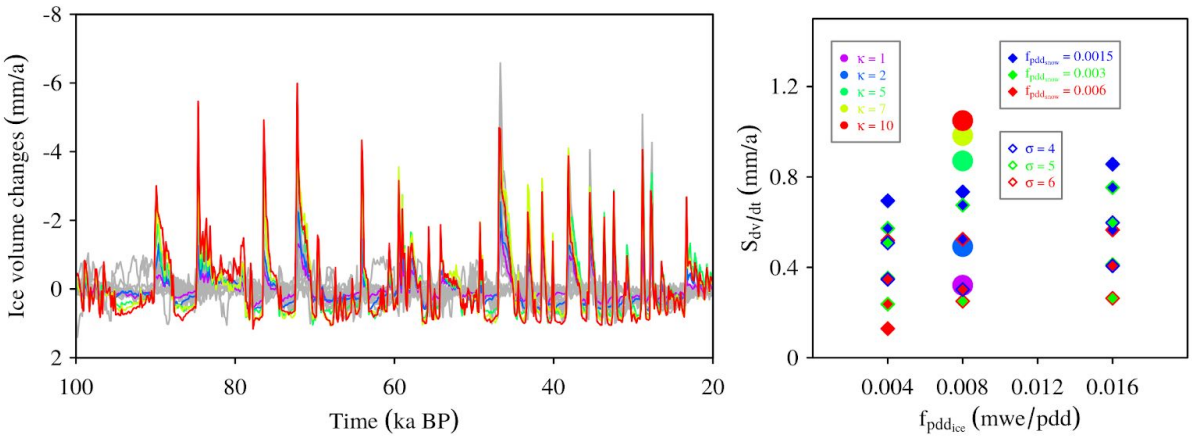

Figure S3 | Left: Time series of the EIS volume changes. Gray trajectories represent the 91 realisations of perturbing the PDD parameters. The sensitivity shown by different values of the ocean heat flux coefficient, **κ**, is included by means of the OCNsrf time series in colors. Right: Scatter plot of the amplitude of the millennial oscillations (standard deviation of the volume changes time series) for the PDD ensemble (diamonds). This amplitude is compared with the one shown by exploring the values of **κ** (from 1 to 10 m/yr/K) in a OCNsrf ensemble (circles). A greater amplitude when forcing with the ocean is found from **κ** = 5 /m/yr/K.

3. On the sensitivity to the calving threshold parameter

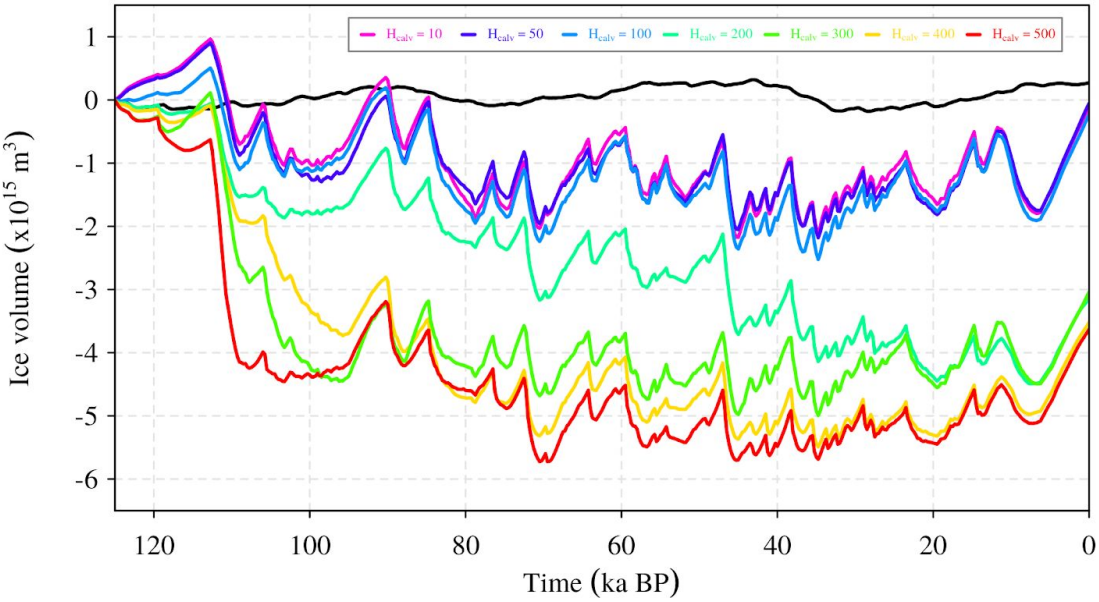

Figure S4 | Volume time series of the EIS for different values of the thickness threshold parameter H_{calv}

4. Surface and basal mass balance fields

Figure S5 shows the SMB and basal mass balance (BMB) anomaly fields. The fields are obtained by choosing the periods around DO12 as in Figure 7 of the main text.

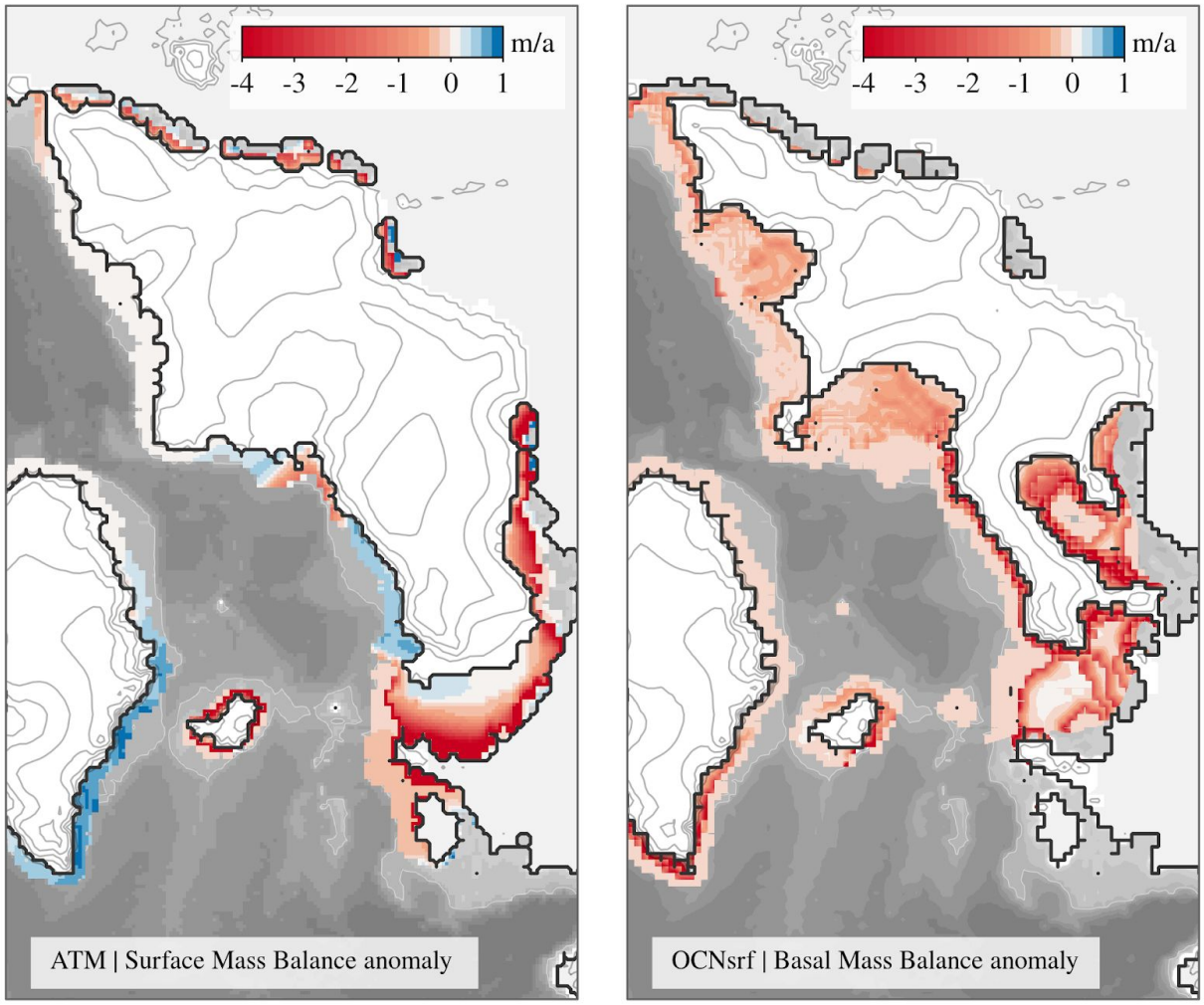

Figure S5 | Surface (left) and basal (right) mass balance anomalies during DO12 (i.e. SMB and BMB fields at 47.5 ka BP minus those fields evaluated at 45.6 ka BP).

5. Orbital and millennial ice-sheet evolution

Figure 4 of the main text shows a trend in ice volume from its initial value (about 21 m SLE) leading to a loss of 8-12 m SLE. As stated in the main text: “This is a consequence of the fact

that no refreezing is allowed and that a positive constant (and spatially uniform) basal melting of 0.1 m/a was imposed. As a consequence, accumulation is not able to compensate for ice loss through basal melt and calving after each ice-mass loss event. Note, however, that background conditions are fixed at 40 ka BP; in a more realistic setup, as time proceeds forward, orbital forcing leading to gradually colder conditions would be expected to aid in the ice regrowth, thereby helping to its growth throughout the LGP." In order to illustrate this explanation, we have performed new simulations including the orbital component of the climatic forcing with and without the millennial forcing. Figure S6 shows the Eurasian ice volume evolution in these cases. It clearly shows that a maximum ice volume around 22 ka BP can be reproduced.

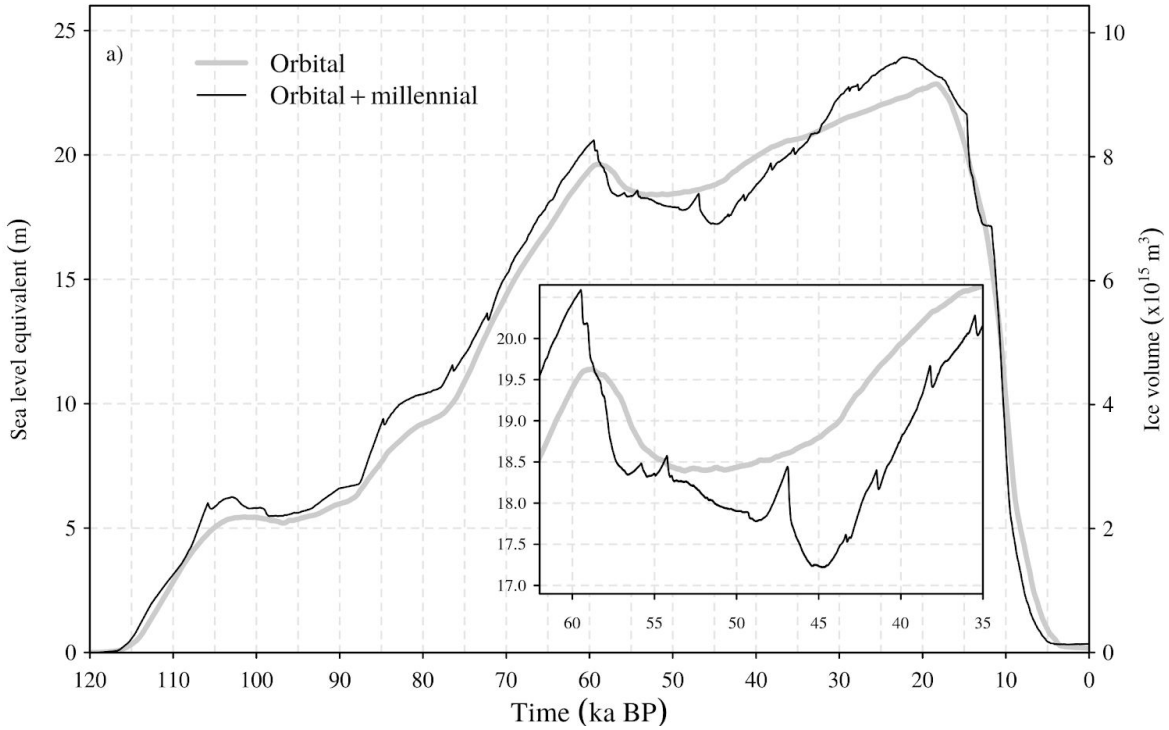

Figure S6 | Eurasian ice volume evolution for the last glacial period when including the orbital forcing alone (grey) and the orbital and millennial components together (black). The inset shows the evolution during MIS3.