Supplementary information for 'The sea-level conundrum – insights from paleo studies'

Mark Siddall, Peter Clark, Bill Thompson, Claire Waelbroeck, Jonathan Gregory, Thomas Stocker

Here we justify that statement in the main report that the sea-level data for TI support the notion that the SL response is rapid following a perturbation but then reduces over time as ice sheets reach a new steady state (i.e., subglacial hydrological system adjusts to increased melt flux, transition from marine-based to land-based ice). One can consider three basic patterns for the sea-level response during TI:

(1) the rate of response increases exponentially with continued warming due to nonlinear feedbacks (i.e., meltwater lubrication of the ice-sheet bed, destruction of buttressing ice shelves of marine-based ice);

(2) tendencies for the acceleration and deceleration of the ice sheet response roughly cancel out so that the response is a steady rate over time; and

(3) the response is rapid following a perturbation but then reduces over time as ice sheets reach a new steady state (i.e., subglacial hydrological system adjusts to increased melt flux, transition from marine-based to land-based ice).

We compare each of these possible response scenarios to sea-level change during TI in figure 1 SI. Based on this evidence we suggest that option 1 (exponential sea-level rise) is extremely unlikely. We note that, the ice-sheet model used for the AR4 prediction of 20th century sea-level rise does not capture the mode of integrated ice-sheet response which is observed during TI [Huybrechts et al. 2004]. Ice-sheet models must be able to capture the full range of the dynamics revealed by the paleo sea-level record if we are to have confidence in projections of future sea-level rise derived from them.

Additional acknowledgements

The authors would like to acknowledge the other workshop participants: Ayako Abe-Ouchi, Morten Andersen, Fabrizio Antonioli, Jonathon Bamber, Edouard Bard, Jorie Clark, Pierre Deschamps, Andrea Dutton, Mary Elliot, Christina Gallup, Natalya Gomez, Peter Huybers, Kenji Kawamura, Meredith Kelly, Kurt Lambeck, Tom Lowell, Jerry Mitrovica, Bette Otto-Bliesner, David Richards, Jenny Stanford, Claudine Stirling, Alex Thomas, Torbjörn Törnqvist, Natalia Vazquez Riveiros, Yusuke Yokoyama, Shiyong Yu. We acknowledge financial and organizational assistance from IMAGES, PAGES and the University of Bern.

References

Alley, R.B., P.U. Clark, P. Huybrechts and I. Joughin (2005), Ice-sheet and sea-level changes, *Science*, *310*, 456-460.

Bard, E., B. Hamelin, M. Arnold, L. Montaggioni, G. Cabioch, G. Faure and F. Rougerie (1996), Sea level record from Tahiti corals and the timing of deglacial meltwater discharge, *Nature*, *382*, 241-244.

Dyke, A. S. in Quaternary Glaciations — Extent and Chronology Part II Vol. 2b (eds Ehlers, J. & Gibbard, P. L.) 373–424 (Elsevier, Amsterdam, 2004).

Huybrechts, P., J. Gregory, I. Janssens, and M. Wild (2004), Modelling Antarctic and Greenland volume changes during the 20th and 21st centuries forced by GCM time slice integrations, *Glob. Planet. Change*, *42*, 83–105.

Jansen, E., J. Overpeck, K.R. Briffa, J.-C. Duplessy, F. Joos, V. Masson-Delmotte, D. Olago, B. Otto-Bliesner, W.R. Peltier, S. Rahmstorf, R. Ramesh, D. Raynaud, D. Rind, O. Solomina, R. Villalba, and D. Zhang, 2007: Palaeoclimate. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller, Eds. Cambridge University Press, pp. 433-497.

Oppenheimer, M., B.C. O'Neill, M. Webster and S. Agrawala (2007), The Limits of Consensus, *Science*, *317*, 1505-1506.

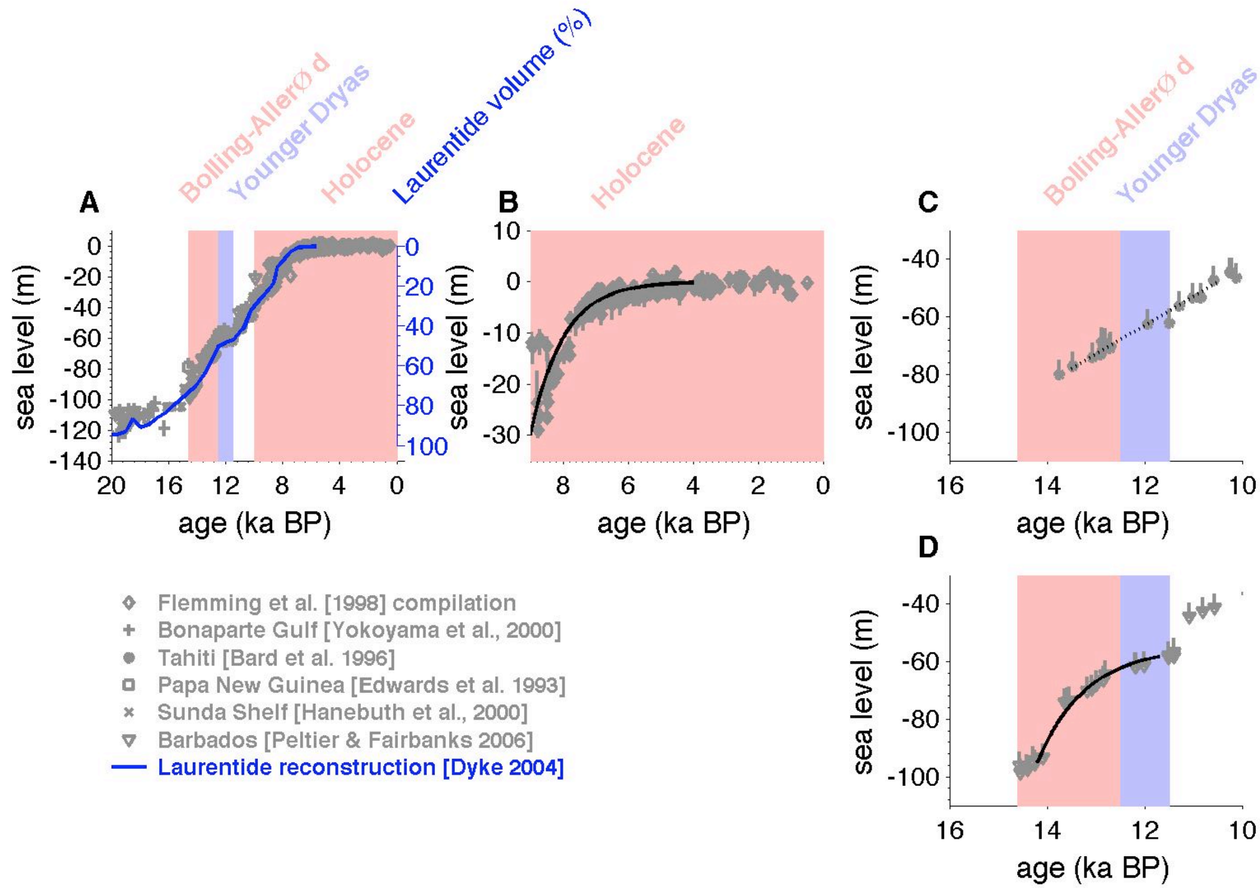
Otto-Bliesner, B.L., S.J. Marshall, J.T. Overpeck, G.H. Miller, A. Hu and CAPE Last Interglacial Project members (2006), Simulating Arctic Climate Warmth and Icefield Retreat in the Last Interglaciation, *Science*, *311*(5768), 1751 – 1753, DOI: 10.1126/science.1120808.

Solomon, A., R. Alley, J. Gregory, P. Lemke and M. Manning (2008), A closer look at the IPCC report, *Science*, *319*, 409-410.

Stirling, C.H., T.M. Esat, K. Lambeck and M.T. McCulloch (1998), Timing and duration of the last interglacial: evidence for a restricted interval of widespread coral reef growth. *Earth Plan. Sci. Lett.*, *160*, 745–762.

Thompson, W.G. and S.L. Goldstein (2005), Open-system coral ages reveal persistent suborbital sea-level cycles, *Science*, *308*(5720), 401–404.

Figure 1SI. Sea level during TI. A) RSL data through the termination at multiple sites, the isostatically corrected record of Fleming et al. [1998] compared with the reconstructed Laurentide volume after Dyke [2004] (right hand axis). Laurentide volume was approximated using the relationship for an ice sheet on a hard bed (log[volume] = 1.23[log[area]$^{-1}$])) [Paterson 1994]. Evidence for the areal retreat of the Laurentide Ice Sheet [Dyke, 2004] is in broad agreement with the sea-level record. B) the isostatically corrected data compilation of Fleming et al. [1998], corrected for glacio-isostasy, hydro-isostasy and rotational effects. Following these results, ESL gradually asymptotes during the early-to-mid Holocene to reach pre-industrial levels C) the medium field response at Tahiti [Bard et al. 1996] showing a linear response over time and D) the medium field response at Barbados [Peltier and Fairbanks 2006] showing a decelerating response over time. Although local isostatic effects affect RSL at both sites, the accelerating response occurs at neither site - there is no evidence for an acceleration of the ice-sheet response over time during TI. Improved understanding of the timing and source of MWP 1a (Fig. 2c,d) [Fairbanks, 1989; Clark et al., 2002] may help to determine whether model 2 or 3 better describes ESL response.



A
B
C
D
Bolling-AllerØd
Younger Dryas
Holocene
Laurentide volume (%)
sea level (m)
age (ka BP)
Flemming et al. [1998] compilation
Bonaparte Gulf [Yokoyama et al., 2000]
Tahiti [Bard et al. 1996]
Papa New Guinea [Edwards et al. 1993]
Sunda Shelf [Hanebuth et al., 2000]
Barbados [Peltier & Fairbanks 2006]
Laurentide reconstruction [Dyke 2004]