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Pliocene constraints on longer term climate sensitivity

Alan Haywood (1), Daniel Hill (2,3), and Daniel Lunt (4)

(1) University of Leeds, School of Earth and Environment, Leeds, United Kingdom (earamh@leeds.ac.uk, 0044 113 343 6716), (2) University of Leeds, School of Earth and Environment, Leeds, United Kingdom (d.j.hill@leeds.ac.uk), (3) British Geological Survey, Keyworth, Nottingham, United Kingdom, (4) University of Bristol, School of Geographical Sciences, Bristol, United Kingdom (d.j.lunt@bris.ac.uk)

Intervals in deep time (i.e. the pre-Quaternary) are being increasingly used as a means to quantify longer term climate sensitivity (hereafter referred to as Earth System Sensitivity). Earth System Sensitivity (ESS) differs from equilibrium climate sensitivity (CS) by including additional feedbacks to a change in atmospheric carbon dioxide (CO_2) concentration from slow responding components of the climate system, such as vegetation and ice-sheets. Warm intervals of the Pliocene epoch (2.7 to 5.2 million years ago), lasting for thousands of years, were likely characterised by CO_2 concentrations 80 to 120 ppmv higher than the pre-industrial era, and therefore provide a potential way to calculate ESS and determine how it differs from equilibrium CS. This task is aided by the availability of geological reconstructions of ice sheets and vegetation that can be used as boundary conditions for global climate models. An initial calculation from Lunt et al. (2010) suggests that on the basis of examining the Pliocene, ESS may be 30 to 50% greater than equilibrium CS. However, this study used geological reconstructions of the ice-sheets and vegetation that have now been improved. Furthermore, the Lunt et al. (2010) study only used a single coupled ocean-atmosphere climate model to produce the initial ESS estimate, so the degree of model dependency in the calculated ESS was unknown. Here we revise estimates of ESS based on the Pliocene using a new ensemble of climate simulations produced by the Pliocene Model Intercomparison Project (PlioMIP), which has provided a multi-model ensemble of Pliocene climate utilising the latest geological reconstructions for vegetation and the ice-sheets as boundary conditions. In the PlioMIP ensemble there is a large spread in the ratio ESS/CS from 1.04 (the IPSL model) to 2.0 (the HadCM3). The ratio for the ensemble mean is 1.5. Therefore, the PlioMIP simulations provide a similar result to the Lunt et al. (2010) study, and show that ESS is greater than equilibrium CS. The new estimates indicate that the ESS/CS ratio is between 1.04 and 2, and imply a best estimate of 1.5.

Caveats to these new calculations of ESS based on the PlioMIP are numerous and include the degree to which models within the ensemble have reached an equilibrium climate condition with imposed Pliocene boundary conditions, the consistency between each groups Pliocene simulation and the simulation used in published estimates of equilibrium CS, and the degree to which the geological record for Pliocene ice sheets and vegetation reflects a response to higher CO_2 concentrations, rather than other factors (i.e. orbital forcing). The latter issue is particularly complex and difficult to assess due to the uncertainties in chronology and correlation inherent within the proxy data that underpin the boundary conditions used by the climate models. We conclude by presenting a new strategy for proxy data collection and modelling designed to overcome some of these stated weaknesses.