An estimate of Earth System Sensitivity from the Pliocene

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(1) INTRODUCTION

One of the cornerstones of climate research is the attempt to characterise the equilibrium global temperature response of the Earth’s climate to a doubling of atmospheric CO2 concentration. However, due to insufficient understanding of key mechanisms and the lack of necessary computational resources, studies have traditionally neglected possible changes to components of the Earth’s climate system which vary over long timescales, such as ice sheets and vegetation. Since there is evidence of periods in Earth history when the climate system may have been at, or close to, equilibrium with elevated CO2, a combined palaeo data and modelling approach can be used to estimate the true long-term response of the Earth System to increased CO2. The mid-Pliocene (about 3 million years ago) provides an ideal case study, as CO2 was higher than pre-industrial, temperature elevated, and ice sheet and vegetation changes relatively well constrained by palaeo proxy data.

Here, we show that the long-term response of the Earth System to elevated CO2 including slow feedbacks (the Earth System sensitivity), is about 50% greater than the more traditional short term response (the Charney sensitivity).

(2) EXPERIMENTAL METHOD

The four drivers of mid-Pliocene warmth relative to pre-industrial are forcings due to elevated CO2 and lower orography, and feedbacks due to modified vegetation, and reduced ice sheet extent and height. The purposes of this study are two-fold: (a) Firstly, to estimate the relative contribution of these four drivers: DT = dTco2 + dToro + dTveg + dTice

To do this we carry out an ensemble of GCM (HadCM3) simulations with various combinations of boundary conditions appropriate for the mid-Pliocene and pre-industrial (see box (3), right). In order to take account of synergistic effects between the forcings and the feedbacks, we carry out a factor separation as follows: dTco2 = 0.5 (|dT| + |dT|) dToro = 0.5 (|dT| + |dT|) dTveg = 0.5 (|dT| + |dT|) dTice = 0.5 (|dT| + |dT|)

Where T is the global annual mean surface temperature in a simulation which has boundary conditions x and y modified from pre-industrial to mid-Pliocene. c = CO2, orog, veg, and ice.

(3) BOUNDARY CONDITIONS

A selection of boundary conditions (CO2, orography, and snow-free albedo) for the seven GCM simulations discussed in this poster.

(4) MODEL EVALUATION

It is first of all important to evaluate the control mid-Pliocene simulation (Tco2) relative to observations. This is shown below, with a comparison of model-predicted climate with post-industrial, temperature elevated, and ice sheet and vegetation changes relatively well constrained by palaeo proxy data.

(5) RESULTS

The Earth System Sensitivity, to a CO2 increase from 280 to 400ppmv, is 2.3 C. For comparison with the ‘Charney’ sensitivity of 1.6 C, the Earth System sensitivity is about 50% greater.

(6) CONCLUSIONS

Whereas the CO2 rise from 280 to 400 ppmv results in a Charney sensitivity of 1.6 C, the Earth System sensitivity is 2.3C, about 50% greater. This is the temperature change expected for a stabilised future climate at 400ppmv (about half the radiative forcing of a CO2 doubling), with equilibrated ice sheets and vegetation. Traditionally, the IPCC have focused on Charney sensitivity, and groups have used Charney equilibrium scenarios to determine the degree of emissions likely to lead to ‘dangerous’ climate change.

Our work argues that the equilibrium climate change associated with an increase of CO2 is likely to be significantly larger than has traditionally been estimated. How long the Earth System takes to reach this equilibrium cannot be addressed in this modelling framework. Given the uncertainties in the timescale for vegetation and ice sheet responses, estimates of the impacts of long-term greenhouse gas stabilisation scenarios should focus on the Earth System sensitivity rather than the traditional Charney sensitivity.