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 resource, 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:

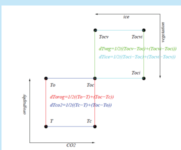
$$DT = dT_{CO2} + dT_{orog} + dT_{veg} + dT_{ice}$$

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:

$$dT_{CO2} = 0.5\,((T_c\text{-}T) + (T_{oc}\text{-}T_o))$$
$$dT_{orog} = 0.5\,((T_o\text{-}T) + (T_{oc}\text{-}T_c))$$
$$dT_{veg} = 0.5\,((T_{ocv}\text{-}T_{oc}) + (T_{ocvi}\text{-}T_{oci}))$$
$$dT_{ice} = 0.5\,((T_{oci}\text{-}T_{oc}) + (T_{ocvi}\text{-}T_{ocv}))$$

Equation 1

Where T_{xy} is the global annual mean surface temperature in a simulation which has boundary conditions x and y modified from pre-industrial to mid-Pliocene. o = orography, c = CO2, i=ice, and v=vegetation.



=7 GCM (HadCM3) simulations

(b) Secondly, and more importantly, by removing the warming effect of orography we are able to provide an estimate of Earth System Sensitivity.

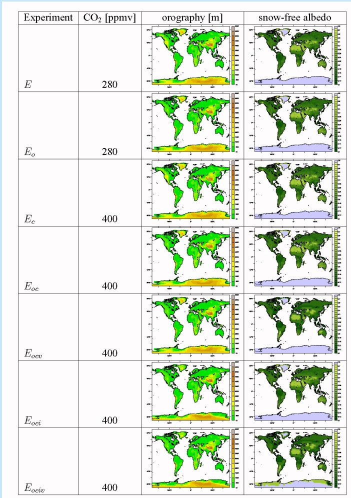
The warming effect of orography has two components - that due directly to the lowered altitude, and additionally the vegetation and ice sheet feedbacks related to this forcing. So, we can write for the earth System Sensitivity, ESS:

$$ESS = dT_{CO2} + f(dT_{veg} + dT_{ice})$$
$$f = |dT_{co2}| / (|dT_{CO2}| + |dT_{orog}|)$$

Equation 2

where f is the fraction of the vegetation and ice feedbacks which can be attributed to CO2. We ass uume that both the vegetation and ice respond to first order to the temperature, so

(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 (T_{ocvi}-T) relative to observations. This is shown below, with a comparison of model-predicted climate with pollen data, and model predicted SSTs with forma assemblages. In both cases the model performs satisfactorily.

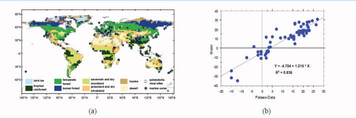


Figure 4: (a) Mid-Pliocene palaeobotanical mega-biomes from the TEVIS dataset (Salzmann *et al.*, 2008) (filled circles), and mega-biomes predicted from BIOME4, forced by the mid-Pliocene GCM climate, following the methodology of Salzmann *et al.* (2009). (b) Regression plot for the mid-Pliocene surface air temperature reconstructions from palaeobotanical data (n=59, Salzmann *et al.*, 2008) versus mid-Pliocene model simulation.

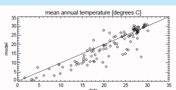
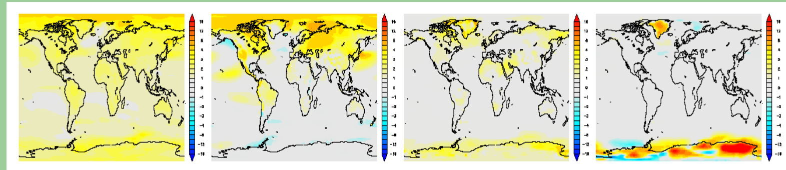


Figure 3: Model-data comparison of SSTs (February and August combined) for our mid-Pliocene simulation and from faunal analysis of planktonic foraminifera (Dowsett, 2007). For comparison with bottom panel of Figure 7 in Haywood and Valdes (2004).

(6) RESULTS (a) - THE CAUSES OF MID-PLIOCENE WARMTH



CO_2 = 1.6℃
='Charney' sensitivity

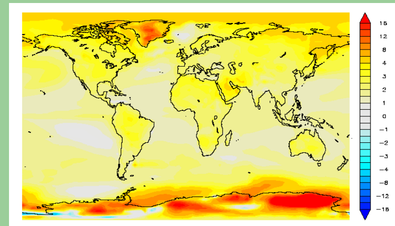
orog = 0.7℃   veg = 0.7℃   ice = 0.4℃

from Equation 1

(7) RESULTS (b) - EARTH SYSTEM SENSITIVITY (ESS)

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.

ie, the Earth System Sensitivity is about 50% greater



ESS = 2.3℃   from Equation 2

(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 thismodelling 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.