Ocean Circulation Changes at the PETM: A fully coupled GCM study

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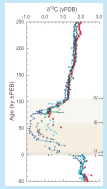
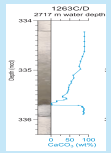
(1) INTRODUCTION

A substantial transient warming of the Earth's surface occurred 55.5 million years ago (Ma) (the 'Paleocene/Eocene Thermal Maximum' or 'PETM'), synchronous with a carbon isotopic excursion (see figure, right upper) interpreted as recording a massive release of carbon to the ocean and atmosphere, and resulting in ocean acidification (see figure, right lower). Although the PETM represents a potential analogue for future global change, little is currently certain about the source, quantity, or rate of carbon release, nor of the impact of major reorganizations in ocean circulation that took place at this time.



Carbon isotopic excursion accross the PETM (Zachos et al., Science, 2005).

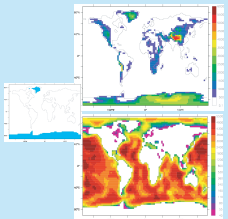


CaCO3 fraction excursion accross the PETM (Zachos et al., Science, 2005).

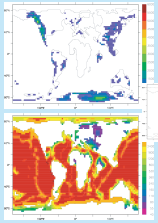
We carry out a suite of 3 fully-coupled simulations of the Eocene, with varying levels of atmospheric CO_2.(2* modern, 4* modern, 6* modern), using the UK Met Office model, HadCM3L. We analyse several aspects of the Eocene climate and its sensitivity to CO_2, including temperature distribution, ocean circulation, and vegetation.

(2) BOUNDARY CONDITIONS

For the HadCM3L Eocene GCM simulations, we use palaeotopography and paleobathymetry reconstructions specific to 50 Ma.

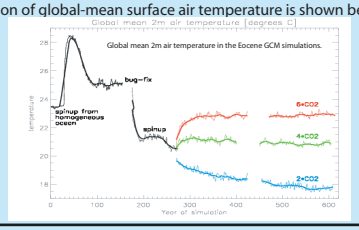


Paleogeographies (orography, top, ice, middle bathymetry, bottom)used in the standard **pre-industrial** HadCM3L GCM simulation.



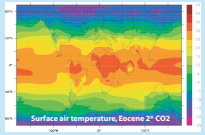
Paleogeographies (orography, top, ice, middle, bathymetry, bottom)used in the **Eocene** HadCM3L GCM simulations.

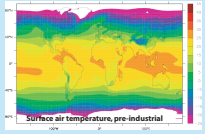
After a period of spin-up, we spin off 3 Eocene simulations, with 3 CO_2 concentrations - 2* modern, 4* modern, and 6* modern. The evolution of global-mean surface air temperature is shown below.

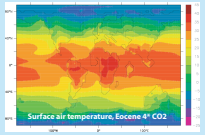


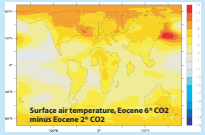
(3) GCM RESULTS

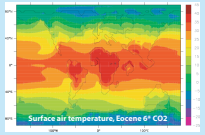
Below are the surface air temperature in the pre-industrial and the 3 Eocene simulations, and an indication of the climate sensitivity.

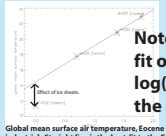








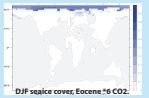




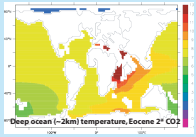
Global mean surface air temperature, Eocene and pre-industrial. Straight line is the best-fit to the Eocene results.

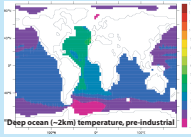
Note linear fit of T to log(CO2) at the Eocene.

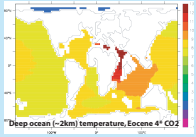
Below is the seaice cover in DJF in the pre-industrial and in the * 2 and *6 CO2 Eocene simulations. Even with *6 CO2, there is still significant winter seaice predicted in the high Arctic.

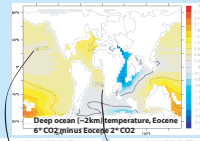


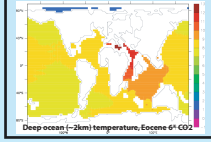
Below are the deep ocean (~2km) temperature in the pre-industrial and the 3 Eocene simulations, and the change 6* minus 2* CO2..

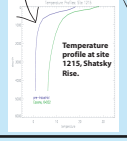


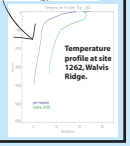




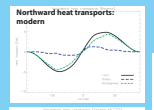


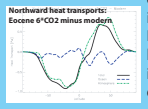


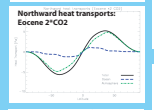


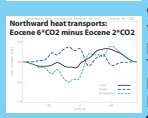


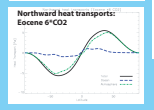
(5) OCEAN CIRCULATION CHANGES



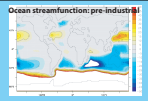


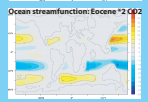


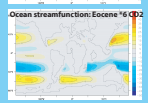


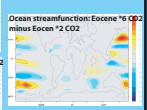


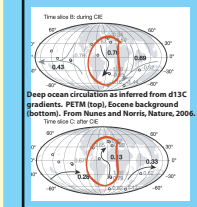
First we examine the ocean heat transports in the *2 and *6 CO2 eocene simulations, and the pre-industrial (left). As expected, in the Eocene, there is enhanced poleward heat transport compared to pre-industrial, associated with the decreased meridional temperature gradient. This enhanced heat transport is carried out predominantly by the atmosphere. The difference in heat transports between the *2 CO2 and *6 CO2 Eocene simulations is less clear, but there are clear ocean heat transport changes in the Southern Hemisphere. The changes in circulation are highlighted in the plots of ocean streamfunction (above right).

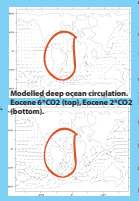






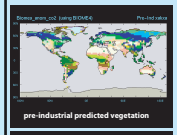


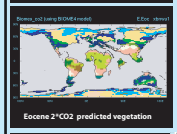


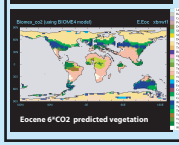


The plots on the far left show possible changes in circulation at the PETM, inferred from changes in gradients of d13C (Nunes and Norris, Nature, 2006). The model results (right) appear to support this interpretation, indicating a reversal in the direction of Atlantic deep water in a high CO2 climate during the Eocene. The model results suggest that the changes in circulation are a possible consequence of elevated greenhouse gas concentrations, rather than a driver of elevated PETM temperatures.

(6) VEGETATION CHANGES







We also use the predicted pre-industrial and Eocene climates to force the BIOME4 vegetation model. Significant changes are seen for the Eocene including the dissappearence of cold tundra vegetation, and the greening of the West Antarctic peninsula. The 6*CO2 simulation results in a decrease of global NPP compared to the 2*CO2 simulation.

(6) CONCLUSIONS

We have carried out fully-coupled simulations of the Eocene, with 3 different CO2 levels: 2*modern, 4* modern, and 6* modern. The global mean surface temperatures scale linearly with log(CO2). The ocean circulation in the models is diagnosed. In particular, there is a reversal in the direction of the deep Atlantic water transport, going from northward in the 2*CO2 simulation to southward in the 6* CO2 simulation, in agreement with recent data (Nunes and Norris, 2006). The model results suggest that the changes in circulation are a possible consequence of elevated greenhouse gas concentrations, rather than a driver of elevated PETM temperatures.