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Sensitivity to CO_2 of the Eocene climate: implications for ocean circulation and clathrate destabilisation

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(1) INTRODUCTION

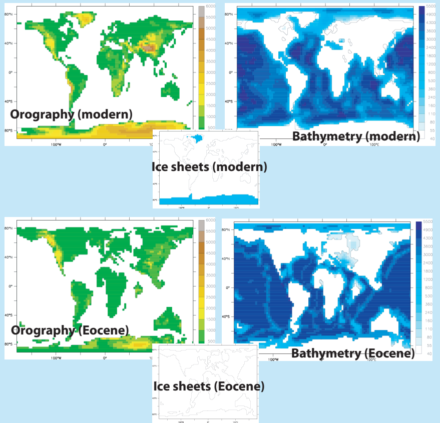
Climate Sensitivity is a key parameter for quantifying the response of the entire Earth System to a perturbation in radiative forcing, via a doubling of atmospheric CO_2 concentration. Here, we investigate how Climate Sensitivity might have varied over geological time. In particular, we investigate the non-linearity of Climate Sensitivity under modern-day and Eocene boundary conditions. We carry out simulations at x1, x2, x4, x8, and x16 CO_2 concentrations, relative to pre-industrial. We then carry out an similar suite of CO_2 simulations but under Eocene boundary conditions (i.e. solar constant, paleotopography and paleobathymetry appropriate for 50 million years ago). The modern simulations are a proxy for future climate change, and the Eocene simulations for the climate of the PETM (Paleocene-Eocene Thermal Maximum, 55.5 Ma).

Here, we focus on the simulations of the Eocene and PETM climates. In particular, there is a dramatic switch in ocean circulation at high CO_2 under Eocene boundary conditions. This is associated with a large increase in sub-surface water temperature in the Atlantic, which is not present in the simulations carried out under modern boundary conditions. The implication is that the PETM event may have been amplified by clathrate destabilisation, related to the ocean circulation change.

(2) EXPERIMENTAL DESIGN

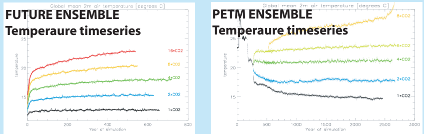
We carry out a suite of fully-coupled atmosphere-ocean simulations, using the UK Met Office model, HadCM3L. We run for two time periods (modern and Eocene), and with a variety of CO_2 concentrations

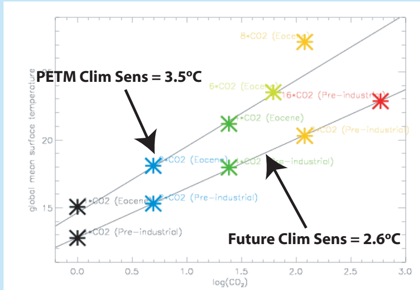
The boundary conditions for the two time periods considered are shown below:



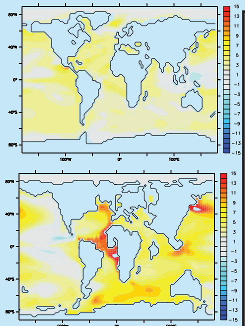
(3) GCM RESULTS

Below are timeseries of global annual mean surface temperature, for our future and PETM ensembles of simulations. Note that the PETM simulations are of the order 2500 years long, whereas the future simulations are around 600 years long.



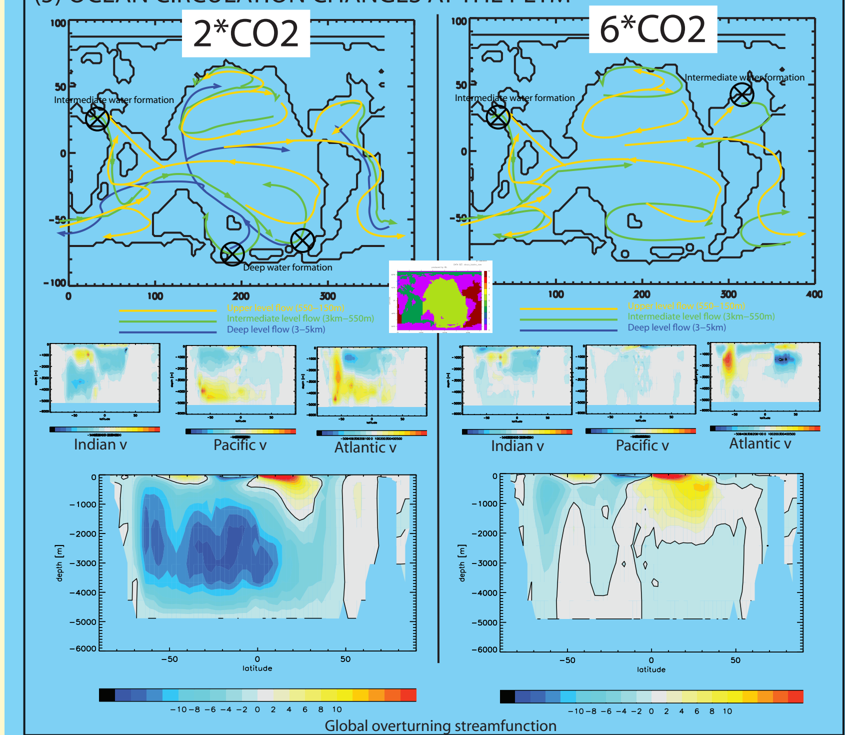


The offset in surface temperature between the future and the PETM is due to the fact that there are no ice sheets in our PETM simulations The greater gradient at the PETM is also due to the lack of permanent ice sheets - a given change in forcing leads to a greater albedo change at the PETM as snow can be melted, whereas in the model ice sheets are fixed. The non-linearity at high CO_2 at the PETM is due to a runaway greenhouse effect. If the model is correct, this puts some sort of limit on the maximum CO_2 concentration likely at the PETM.



The plots on the left show the temperature difference between low and high CO2 at a depth of ~150m. It is clear that under Eocene boundary conditions, the response of the ocean to increased CO2 is very different to modern, especially in the Atlantic. It is possible that these elevated temperatures could have caused further temperature increase by clathrate destabilisation.

(5) OCEAN CIRCULATION CHANGES AT THE PETM



(6) CONCLUSIONS

We have carried out 2 suites of CO2 sensitivity studies, under modern and Eocene boundary conditions. The modern suite is an analogue for future climate change; the Eocene suite is an analogue for the PETM. The Eocene suite shows a dramatic change in ocean circulation which occurs between 2* and 6* CO2 atmospheric concentrations. At high CO2, the ocean is generally more stratified, with little or no deep water formation. At low CO2, the cold air over Antarctica helps to drive deep water formation in the Southern Ocean. Associated with this is a huge increase in sub-surface ocean temperature in the tropical Atlantic (more than 15°C) at high CO2, (not present under pre-industrial boundary conditions).

These circulation-induced elevated temperatures would enhance the destabalization of methane hydrates and potentialy amplifying PETM greenhouse warming.