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The Arctic Cryosphere in the mid-Pliocene and the future....

(and using the Pliocene to estimate long-term climate sensitivity)

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The Arctic cryosphere in the mid-Pliocene and the future

(1) Introduction

The mid-Pliocene (ca 3 Myr ago) was a relatively warm period, with increased atmospheric CO2 relative to pre-industrial. It has therefore been highlighted as a possible palaeo-analogue for the future. However, changed vegetation patterns, orography and smaller ice sheets also influenced the Mid-Pliocene climate. Here, using a general circulation model (HadCM3) and ice-sheet model (GLIMMER), we determine the relative contribution of vegetation and soils, orography and ice, and CO2 to the Mid-Pliocene Arctic climate and cryosphere.

(2) GCM and ice sheet model simulations

We first carry out an ensemble of GCM simulations with the UK Met Office GCM, HadCM3, incorporating various combinations of mid-Pliocene, pre-industrial, and future boundary conditions:

Table 1. Summary of GCM simulations. (M is for pre-industrial (modern) boundary conditions, P is for Mid-Pliocene boundary conditions and F is for future boundary conditions (F_1 is 560 ppmv CO_2 and F_2 is 1120 ppmv CO_2).)

simulation name	CO_2	orography and ice	vegetation and soils
Mod	M	M	M
$Mod_{plioveg}$	M	M	P
$Plio_{modCO_2}$	M	P	P
Plio	P	P	P
$Mod_{400\ ppmv}$	P	M	M
$Mod_{560\ ppmv}$	F_1	M	M
$Mod_{1120\ ppmv}$	F_2	M	M

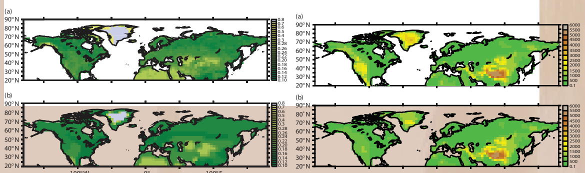


Figure 1. Vegetation and soil boundary conditions. Northern Hemisphere snow-free surface albedo in (a) the pre-industrial and (b) the Mid-Pliocene.

we then use the predicted climatologies to force the GLIMMER ice sheet model offline, over Greenland.

orography boundary conditions for (a) pre-industrial and (b) mid-Pliocene

(3) Results

The figures below show the results for the mid-Pliocene (left) and the future (right, from the GCM (upper) and from the ice sheet model (lower).

mid-Pliocene

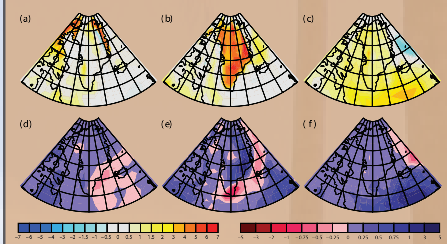


Figure 4. Surface climate anomalies associated with a change from pre-industrial to Mid-Pliocene. (a–c) Simulated surface temperature change (8C) for (a) $Mod_{plioveg}$K Mod, (b) $Plio_{modCO_2}$K $Mod_{plioveg}$ and (c) Plio K $Plio_{modCO_2}$. (d–f) Simulated precipitation change (mm d^{K1}) for (d) $Mod_{plioveg}$K Mod, (e) $Plio_{modCO_2}$K $Mod_{plioveg}$ and (f) Plio K $Plio_{modCO_2}$.

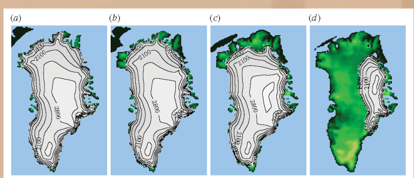


Figure 5. Ice-sheet configurations. (a) *Mod*, (b) $Mod_{plioveg}$, (c) $Plio_{modCO_2}$ and (d) *Plio*.

Future

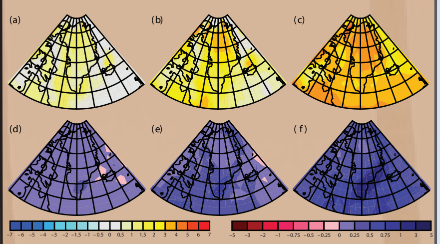


Figure 6. Surface climate anomalies associated with a change from pre-industrial to the future. (a–c) Simulated surface temperature change (8C) for (a) $Mod_{400\ ppmv}$K Mod, (b) $Mod_{560\ ppmv}$K Mod and (c) $Mod_{1120\ ppmv}$K Mod. (d–f) Simulated precipitation change (mm d^{K1}) for (d) $Mod_{400\ ppmv}$K Mod, (e) $Mod_{560\ ppmv}$K Mod and (f) $Mod_{1120\ ppmv}$K Mod.

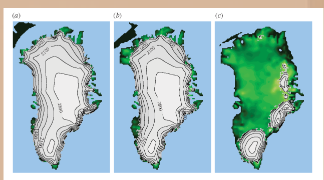
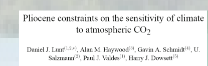


Figure 7. Ice-sheet configurations. (a) $Mod_{400\ ppmv}$, (b) $Mod_{560\ ppmv}$ and (c) $Mod_{1120\ ppmv}$.

(4) Conclusions

Compared with pre-industrial, we find that increased Mid-Pliocene CO2 contributes 35 per cent, lower orography and icesheet feedbacks contribute 42 per cent, and vegetation changes contribute 23 per cent of Arctic temperature change. The simulated mid-Pliocene Greenland ice sheet is substantially smaller than that ofmodern,mostly due to the higher CO2. However, our simulations of future climate change indicate that the same increase in CO2 is not sufficient to melt the modern ice sheet substantially. We conclude that, although the Mid-Pliocene resembles the future in some respects, care must be taken when interpreting it as an exact analogue due to vegetation and ice-sheet feedbacks. These act to intensify Mid-Pliocene Arctic climate change, and act on a longer time scale than the century scale usually addressed in future climate prediction. This concept is investigated further in the 2nd part of this poster, below.



Using the Pliocene to estimate long-term climate sensitivity (the "Earth System sensitivity")

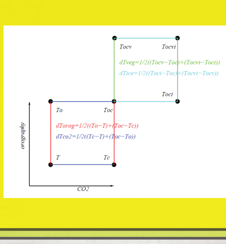
(1) Introduction and Methods

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 modern, temperature elevated, and ice sheet and vegetation changes relatively well constrained by palaeo proxy data.

We carry out a set of GCM simulations to determine the relative contribution of CO2, orography, vegetation, and ice to mid-Pliocene warmth. We then remove the orography contribution, and a fraction of the vegetation and ice feedbacks associated with orography, to obtain and estimate of "Earth System sensitivity" - the response of the earth System on long timescales to a given CO2 forcing.

We name a GCM simulation which has boundary conditions x and y modified from pre-industrial to mid-Pliocene as E_{xy}. The four boundary conditions considered are atmospheric CO_2 (c), orography (o), vegetation (v), and ice sheets (i). Thus, a pre-industrial simulation is E, a mid-Pliocene simulation is E_{ociv}, and *e.g.* a simulation with pre-industrial ice and vegetation but mid-Pliocene orography and CO_2 is E_{oc}. The corresponding temperature distributions in these simulations we name T, T_{ociv}, and T_{oc} respectively. For the factor separation, to take account of nonlinear interactions between the orography and CO_2 forcings and between the vegetation and ice feedbacks, in a way which is symmetric whether the control climate is considered to be the pre-industrial or the mid-Pliocene, we define

$$
\begin{aligned}
dT_{CO_2} &= \frac{1}{2}((T_c - T) + (T_{oc} - T_o)),\\
dT_{orog} &= \frac{1}{2}((T_o - T) + (T_{oc} - T_c)),\\
dT_{veg} &= \frac{1}{2}((T_{ocv} - T_{oc}) + (T_{ociv} - T_{oci})),\\
dT_{ice} &= \frac{1}{2}((T_{oci} - T_{oc}) + (T_{ociv} - T_{ocv})). \qquad (5)
\end{aligned}
$$



(2) Results and Conclusions

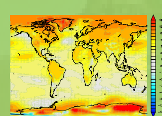


Figure 1: Simulated surface temperature change [°C], mid-Pliocene minus pre-industrial.

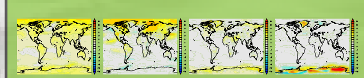


Figure 2: Temperature change due to CO_2 (dT_{CO_2}), orography (dT_{orog}), vegetation (dT_{veg}), and ice (dT_{ice}); as calculated from Equation 5.

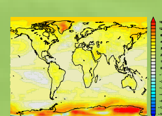


Figure 3: Earth System sensitivity (ESS, Equation 4) to a stabilisation of CO_2 at 400ppmv, including slow vegetation and ice feedbacks. For comparison with Figure 2a which shows the Charney sensitivity for the same forcing.

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Figure 1 shows the temperature change relative to modern in our mid-Pliocne simulation.

Figure 2 shows the partitioning into the separate components. As a global average, of the total mid-Pliocene 3.3oC temperature change, 1.6oC is from the CO2 forcing (dTCO2), 0.7oC is from the orography forcing (dTorog), 0.7oC is from the vegetation feedback (dTveg), and 0.4oC is from the ice feedback (dTice). dTCO2 (Figure 2a) corresponds to the temperature change from a traditional CO2 Charney sensitivity experiment.

The long-term response of the Earth System to elevated CO2 including slow feedbacks (the Earth System sensitivity, Figure 3), is about 50% greater than the more traditional short term response (the Charney sensitivity). This higher sensitivity should be considered when developing and interpreting atmospheric CO2 stabilisation targets.