A POSSIBLE LATE-OLIGOCENE EVOLUTIONARY NICHE FOR C4 GRASSES?

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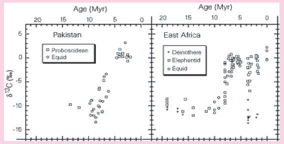
(1) INTRODUCTION

C4 plants are physiologically adapted to conditions of low atmospheric CO2 concentration, high temperature and low water availability, and under such conditions, they have a competitive advantage compared to C3 plants.

The Late Miocene expansion of C4 grasses has been documented through changes in d13C of fossil mammalian tooth enamel, reflecting the balance of C3 and C4 vegetation in the mammalian diet.



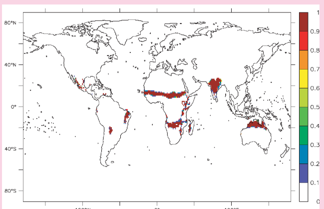
The expansion of C4 grasses in the Late Miocene, 8-06MyrBP, Cerling et al, Nature, 1997.

This expansion has been attributed to decreasing levels of atmospheric CO2 through the early to mid-Miocene, or changes in seasonal patterns of precipitation.

In this poster, we present evidence from modelling studies that appears to indicate that climatic conditions were in fact favourable for C4 plants prior to their expansion in the Late Miocene.

(2) VALIDATION OF LPJ VEGETATION MODEL

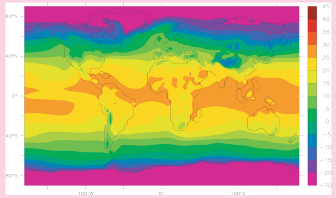
The current distribution of C4 grasses is concentrated in sub-tropical regions, with a maximum in the tropical and warm-temperate grasslands of the Sahel and southern Africa, reflecting the advantage that C4 grasses have over C3 plants in hot, arid regions.



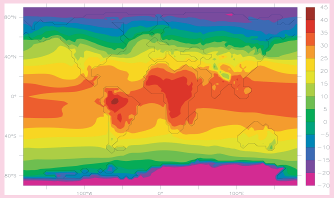
Fractional coverage of C4 grasses, simulated by the LPJ vegetation model, when forced by the CRU climatology.

(3) GCM-SIMULATED CLIMATES

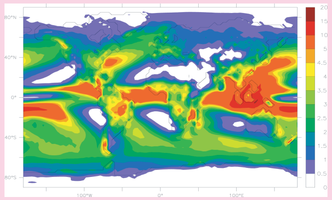
We use the UK Met Office atmosphere-ocean coupled model, HadCM3L, to simulate the pre-industrial and Late Oligocene (Chattian, 27MyrBP) climate. The tectonic changes are from a reconstruction by Paul Markwick. We set CO2 to 3x pre-industrial for the Chattian.



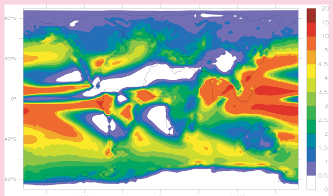
HadCM3L simulated temperature, pre-industrial



HadCM3L simulated temperature, late Oligocene, 27MyrBP



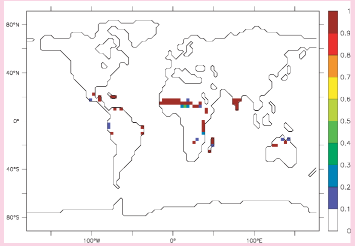
HadCM3L simulated precipitation, pre-industrial



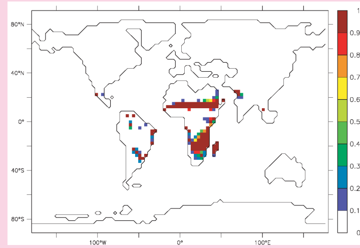
HadCM3L simulated precipitation, late Oligocene, 27MyrBP

(4) VEGETATION MODEL RESULTS

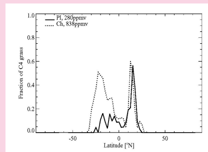
We then use the pre-industrial and late-Oligocene simulated climates (temperature, precipitation, and cloud-cover) as input to the LPJ vegetation model. This predicts fractions of various plant functional types, including C4 grasses.



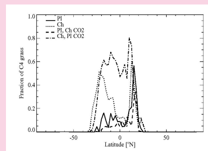
Fractional coverage of C4 grasses, simulated by the LPJ vegetation model, when forced by the pre-industrial (left) and late-Oligocene (right) HadCM3L climatology.



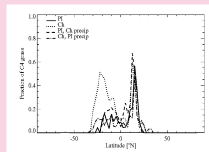
Clearly, the LPJ model is predicting not only a significant C4 grass population, but actually increased from pre-industrial. The zonal mean predicted C4 fraction in the two simulations is shown below, left.
In order to understand these differences better, we also carry out simulations with the late-Oligocene climate, but pre-industrial CO2, and vice-versa. The results are shown below, middle. This shows that the increased late-Oligocene CO2 is massively decreasing the potential for C4 plant growth. We also carry out simulations in which the precipitaiton is reversed between the two simulations (below, right). This shows that the low precipitation at the late-Oligocene over southern Africa is increasing the C4 plant fraction. Overall, the principal factor behind the modelled increase in C4 grasses at the late Oligcene is the increased temperatures., which dominates over the increased CO2.



predicted zonal mean C4 fraction, pre-industrial and late Oligocene



predicted zonal mean C4 fraction, with reversed CO2



predicted zonal mean C4 fraction, with reversed precip

(5) DISCUSSION AND CONCLUSIONS

We have found that the LPJ vegetation model, when forced by clmate predicted by the HadCM3L GCM, predicts significant C4 grasses at the late-Oligocene, (Chattian, 27MyrBP); in fact, a greater population than for the pre-industrial. The data indicates that in reality, C4 grasses did not expand until approximately 8MyrBP, ~20Myr later!

Sensitivty studies show that this increase is mainly due to the higher simulated temperatures at the Chattian, and also the drier climate in southern Africa. It is despite the high CO2 levels at the Chattian, which significantly decrease the C4 population. The change in land-sea mask and cloud cover make very little difference to the predicted C4 distributions (not shown)

So, if this evolutionary niche existed at this time, why was it not filled until ~20 million years later? One possibility is that the simulated GCM climates are wrong, and that a better forcing climate would result in much reduced Chattian C4 grasses. We think that this is unlikely, as sensitivity studies have shown that the result is quite robust, and C4 grasses are actually predicted for a wide variety of Phanerozoic climates (not shown), with various land-sea masks and CO2 concentrations. Another possibility is that the vegetation model is wrong. We get a very similar response when using the TRIFFID vegetation model (results not shown); however it could be that neither model properly represents the effects of high CO2 levels on vegetation.

Another possibility is that C4 grasses took a long time to evolve, despite the climatic conditions being favourable for them to do so. We think that this is the most likely explanation.