C_4 Grasses and Climate in the Late Oligocene? A Modelling Study

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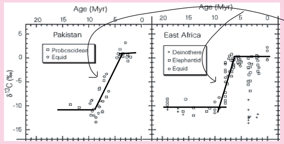
(1) INTRODUCTION

C_4 plants are physiologically adapted to conditions of low atmospheric CO_2 concentration, high temperature and low water availability, and under such conditions, they have a competitive advantage compared to C_3 plants.

The Late Miocene expansion of C_4 grasses has been documented through changes in $\delta^{13}C$ of fossil mammalian tooth enamel, reflecting the balance of C_3 and C_4 vegetation in the mammalian diet.



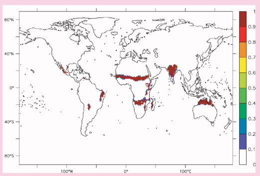
The expansion of C_4 grasses in the Late Miocene, 8-6 Ma, Cerling et al, Nature, 1997.

This expansion has been attributed to decreasing levels of atmospheric CO_2 through the Early to Mid Miocene, or changes in seasonal patterns of precipitation.

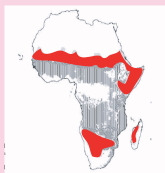
In this poster, we use a GCM and a 'state of the art' vegetation model to test to what extent these observations are reproducible, and to test various hypotheses for their ultimate cause.

(2) VALIDATION OF LPJ VEGETATION MODEL

The current distribution of C_4 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 C_4 grasses have over C_3 plants in hot, arid regions. This agrees reasonably well with stable savanna data from Sankaran et al (2005).



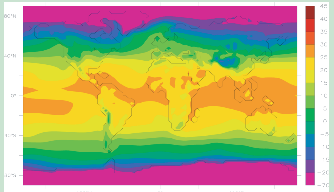
Fractional coverage of C_4 grasses, simulated by the LPJ vegetation model, when forced by a present day observed climatology.



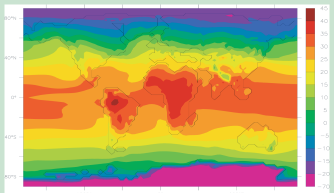
African Savanna from Sankaran et al. (2005). Stable savannas (for comparison with model, left, are in red)

(3) GCM-SIMULATED CLIMATES

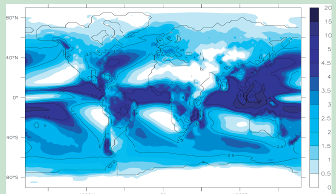
We use the UK Met Office atmosphere-ocean coupled model, HadCM3L, to simulate the pre-industrial and Late Oligocene (27 Ma) climate. The reason for this precise date is fairly arbitrary - it is long enough before the observed transition to C_4 grasses to have a well-defined basis for comparison. The continental tectonic changes are from a reconstruction by Paul Markwick. We set CO_2 to 3x pre-industrial for the Chattian.



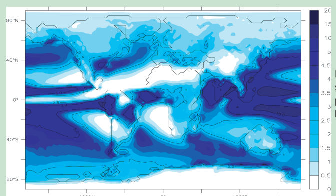
HadCM3L simulated temperature, pre-industrial



HadCM3L simulated temperature, Late Oligocene, 27 Ma



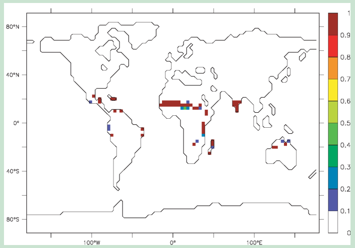
HadCM3L simulated precipitation, pre-industrial



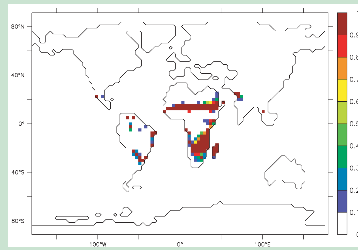
HadCM3L simulated precipitation, Late Oligocene, 27 Ma

(4) VEGETATION MODEL RESULTS

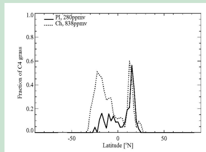
We then use the pre-industrial and Late Oligocene simulated climates (temperature, precipitation, and cloud-cover) as input to the LPJ vegetation model. This predicts fractions of various plant functional types, including C_4 grasses.



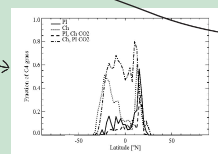
Fractional coverage of C_4 grasses, simulated by the LPJ vegetation model, when forced with the pre-industrial (left) and late-Oligocene (right) HadCM3L climatology.



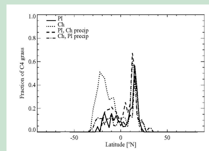
Clearly, the LPJ model is predicting not only a significant C_4 grass population, but actually increased from pre-industrial. The zonal mean predicted C_4 fraction in the two simulations is shown below, left.
In order to understand these differences better, we also carry out simulations with the Late Oligocene climate, but pre-industrial CO_2, and vice-versa. The results are shown below, middle. This shows that the increased Late Oligocene CO_2 is massively decreasing the potential for C_4 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 C_4 plant fraction. Overall, the principal factor behind the modelled increase in C_4 grasses at the Late Oligcene is the increased temperature, which dominates over the increased CO_2.



predicted zonal mean C_4 fraction, pre-industrial and late Oligocene



predicted zonal mean C_4 fraction, with reversed CO_2



predicted zonal mean C_4 fraction, with reversed precip

(5) DISCUSSION AND CONCLUSIONS - see our submitted paper for more information!

We have found that the LPJ vegetation model, when forced by clmate predicted by the HadCM3L GCM, predicts significant C_4 grasses at the late-Oligocene, (27MyrBP); in fact, a greater population than for the pre-industrial. The data indicates that in reality, C_4 grasses did not expand until approximately 8MyrBP, ~20Myr later!

Sensitivty studies show that the modelled increase in Late Oligocene C_4 grasses is mainly due to the higher simulated temperatures at the Chattian, and also the drier climate in southern Africa. It is despite the high CO_2 levels at the Chattian, which significantly decrease the C_4 population. The change in land-sea mask and cloud cover make very little difference to the predicted C_4 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 C_4 grasses. We think that this is unlikely, as sensitivity studies have shown that the result is quite robust, and C_4 grasses are actually predicted for a wide variety of Phanerozoic climates (not shown), with various land-sea masks and CO_2 concentrations. Another possibility is that the vegetation model is wrong. We get a very similar response when using the TRIFFID vegetation model (see submitted paper); however it could be that neither model properly represents the effects of high CO_2 levels on vegetation.

Alternatively, it is possible that C_4 grasses took a long time to evolve, despite the climatic conditions being favourable for them to do so for several million years. Or that the observed shift in $\delta^{13}C$ is in fact reflecting the changing habits/evolution of grazers.