C₄ Grasses and Climate in the Late Oligocene?  
A Modelling Study

D.J. Lunt (1,2), I. Ross (1), P.J. Hopley (1), P.J. Valdes (1)
(1) BRIDGE (Bristol Research Initiative for the Dynamic Global Environment, University of Bristol, UK
(2) British Antarctic Survey, UK

(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 δ¹³C of fossil mammalian tooth enamel, reflecting the balance of C₃ and C₄ vegetation in the mammalian diet.

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 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 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. This agrees reasonably well with stable savanna data from Sankaran et al (2005).

(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 C₄ grasses to have a well-defined basis for comparison. The continental tectonic changes are from a reconstruction by Paul Markwick. We set CO₂ to 3x pre-industrial for the Chattian.

Fractional coverage of C₄ grasses, simulated by the HadCM3L GCM, is in red. The 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 precipitation 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 Oligocene is the increased temperature, which outweighs over the increased CO₂.

(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.

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 precipitation 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 Oligocene is the increased temperature, which outweighs over the increased CO₂.

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

We have found that the LPJ vegetation model, when forced by climate predicted by the HadCM3L GCM, predicts significant C₄ grasses at the Late Oligocene (27 Myr BP). In fact, a greater proportion than for the pre-industrial. This indicates that in reality, C₄ grasses did not expand until approximately 4 Myr BP – 8 Myr later!

Sensitivity studies show that the modelled increase in Late Oligocene C₄ 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 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).

Alternatively, it is possible that C₄ 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 δ¹³C is in fact reflecting the changing habits/evolution of grazers.