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Mechanistic modelling of Middle Eocene atmospheric carbon dioxide using fossil plant material

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Various proxies (such as pedogenic carbonates, boron isotopes or phytoplankton) and geochemical models were applied in order to reconstruct palaeoatmospheric carbon dioxide, partially providing conflicting results. Another promising proxy is the frequency of stomata (pores on the leaf surface used for gaseous exchange). In this project, fossil plant material from the Messel Pit (Hesse, Germany) is used to reconstruct atmospheric carbon dioxide concentration in the Middle Eocene by analyzing stomatal density. We applied the novel mechanistic-theoretical approach of Konrad et al. (2008) which provides a quantitative derivation of the stomatal density response (number of stomata per leaf area) to varying atmospheric carbon dioxide concentration. The model couples 1) C3-photosynthesis, 2) the process of diffusion and 3) an optimisation principle providing maximum photosynthesis (via carbon dioxide uptake) and minimum water loss (via stomatal transpiration). These three sub-models also include data of the palaeoenvironment (temperature, water availability, wind velocity, atmospheric humidity, precipitation) and anatomy of leaf and stoma (depth, length and width of stomatal porus, thickness of assimilation tissue, leaf length).

In order to calculate curves of stomatal density as a function of atmospheric carbon dioxide concentration, various biochemical parameters have to be borrowed from extant representatives. The necessary palaeoclimate data are reconstructed from the whole Messel flora using Leaf Margin Analysis (LMA) and the Coexistence Approach (CA). In order to obtain a significant result, we selected three species from which a large number of well-preserved leaves is available (at least 20 leaves per species).

Palaeoclimate calculations for the Middle Eocene Messel Pit indicate a warm and humid climate with mean annual temperature of approximately 22°C, up to 2540 mm mean annual precipitation and the absence of extended periods of drought. Mean relative air humidity was probably rather high, up to 77%. The combined results of the three selected plant taxa indicate values for atmospheric carbon dioxide concentration between 700 and 1100 ppm (probably about 900 ppm).

Reference:

Konrad, W., Roth-Nebelsick, A., Grein, M. (2008). Modelling of stomatal density response to atmospheric CO2. Journal of Theoretical Biology 253(4): 638-658.