Quantifying effect of increasing pCO_2 of air on Net Isotopic fractionation during Tree-ring cellulose deposition in C_3 plants

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Existing since last 100 million years, C_3 plants represent approximately 95% of Earth's plant biomass. Many of these are ring-bearing trees whose yearly augmentation can be dated using dendrochronological techniques. Part of this augmentation is in the form of stable cellulose with an isotopic composition decided by fractionations during CO_2 diffusion, carboxylation and deposition.

Farquar et al, 1982 quantified the net carbon isotopic fractionation (d) during cellulose formation as:

$$d(‰) = \delta^{13}C_p - \delta^{13}C_a = a + (b-a)\frac{c_i}{c_a} + B\frac{c_i - c_c}{c_a} \qquad (1)$$

where: c_a = Atmospheric pCO_2; c_i = Leaf interstitial pCO_2; c_c = pCO_2 at cellulose deposition site; $\delta^{13}C_a$ = $\delta^{13}C$ of Atmospheric CO_2; $\delta^{13}C_p$ = $\delta^{13}C$ of Tree Cellulose; a = Carbon Isotopic fractionation due to Diffusion; b = Carbon Isotopic fractionation due to Carboxylation (a and b are taken as constant).

From Equation (1), we can see that d vs c_a plot should have zero or negative slope. But, out of 10 natural datasets with tree $\delta^{13}C$ data chosen for this work, three sets had expected trends (zero/negative) in d-variation with pCO_2 (r= - 0.12 to 0.53). Other seven sites, however, show positive trends (r = 0.74 to 0.93; significance level > 90%).

Two kinds of modifications were required for application of Farquhar model to natural trees. (i) The variables c_i and c_c are not measurable in these cases and need to be estimated by some alternative means (after Evans and Caemmerer, 1996). (ii) The reason for some stations showing positive instead of negative slope as predicted by Farquar et al may be because a and b were not constant but varied with meteorological parameters. Putting all these modifications in the equation (1), we get:

$$d = a_1T + a_2V + (b_1 - a_1)\gamma Tz - a_2\gamma Vz + (e_2 - e_1)\gamma z + e_1 \qquad (2)$$

where, a_1 and a_2 quantify the dependencies of a on temperature and vapour pressure respectively, b_1 quantifies the dependency of b on temperature, e_1 and e_2 are non-meteorologically dependent part of a and b respectively, and γ is the proportionality constant between z and $\frac{c_i}{c_a}$.

Testing of various processing schemes of $\delta^{13}C_p$ data in equation (2) reveals that the model performs well only after the correction factor (after Feng and Epstein, 1996) is applied. So, the final form of d turns out to be:

$$d + 6.4 - hc_a = (a + (b-a)c_i/c_a \ = a_1T + a_2V + (b_1 - a_1)\gamma Tz - a_2\gamma Vz + (e_2 - e_1)\gamma z + e_1) \qquad (3)$$

Notably, the factor (hc_a) in equation (3) needs to be applied for both higher and lower ranges of c_a spanning the entire last century. This means that this modified value is important in terms of tree chemistry and observed only in presence of significant and persistent temporal trend in c_a. After multiple runs in the testing period, we have estimated the best value of h is in the range of 0.27 – 0.64 for the 10 sites and species tested. Although this is higher than the values used in past works (which took a and b constant), it is justified by considering the fact that the last few decades experienced unprecedented rise in both temperature and c_a which must have affected the tree chemistry and as a result the carbon isotope fractionation.

References

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