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# Modelling leaf water isotope composition

a crossroad between plant physiology, fluid mechanics and applied mathematics

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## I. RATIONALE

### Why studying leaf water <sup>18</sup>O/<sup>16</sup>O and D/H signals?

The <sup>18</sup>O/<sup>16</sup>O and D/H ratios of leaf water are useful signals for studying the carbon and water budgets of terrestrial ecosystems as they:

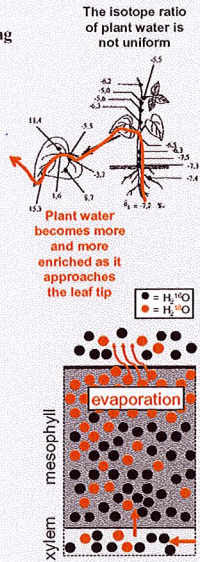
- ...impact the isotope ratio of plant material allowing:
  - to determine changes in stomatal conductance and crop yield
  - to do paleoclimate reconstructions by tree ring analysis
- ...affect atmospheric water vapour (<sup>18</sup>O, D) allowing:
  - to partition evaporation from transpiration
  - to study water redistribution and recycling by plants
- ...affect atmospheric CO<sub>2</sub> (<sup>18</sup>O) allowing:
  - to partition respiration from photosynthesis (one day!)
- ...affect atmospheric O<sub>2</sub> (<sup>18</sup>O) (Dole effect) allowing:
  - paleo-reconstructions of terrestrial vs. marine productivity

### Why leaf water is enriched relative to sap water?

Schematically, leaf water can be separated in two water reservoirs: the xylem and the mesophyll.

Water enters the leaf through the xylem and evaporates on the mesophyll 'walls'.

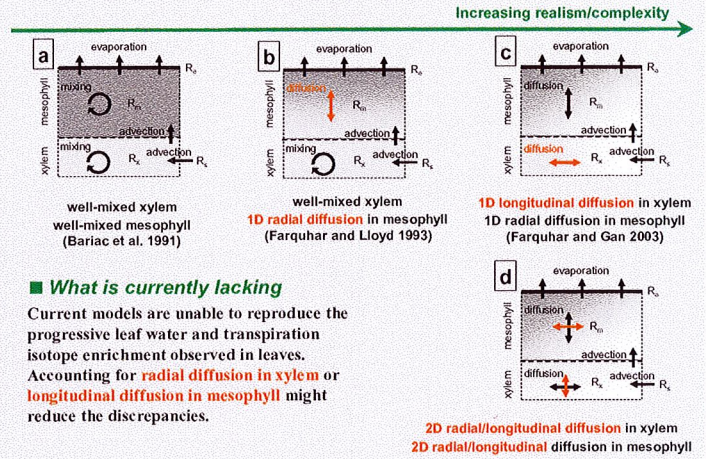
Light water molecules (H<sub>2</sub><sup>16</sup>O) evaporate and diffuse more rapidly than heavy water molecules (H<sub>2</sub><sup>18</sup>O or HDO) which creates an isotopic enrichment in the mesophyll (see Figure).



## II. OBJECTIVES

### Existing leaf water isotopic enrichment models

In all models the advection of water and isotopic enrichment through evaporation are accounted for but, depending on their degree of realism, the isotopic composition of leaf water in each reservoir may be uniform (complete mixing) or not (diffusion)

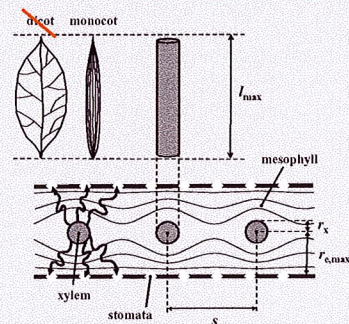


### What is currently lacking

Current models are unable to reproduce the progressive leaf water and transpiration isotope enrichment observed in leaves. Accounting for radial diffusion in xylem or longitudinal diffusion in mesophyll might reduce the discrepancies.

## III. MODEL DESCRIPTION

### Model leaf and model assumptions



Leaf xylem = parallel, cylindrical veins  
 Mesophyll = planar reservoir surrounding the leaf veins  
 2D advection/diffusion with cylindrical symmetry in xylem  
 2D advection/diffusion with planar symmetry in mesophyll  
 Tortuosity of water path in radial direction in both xylem and mesophyll

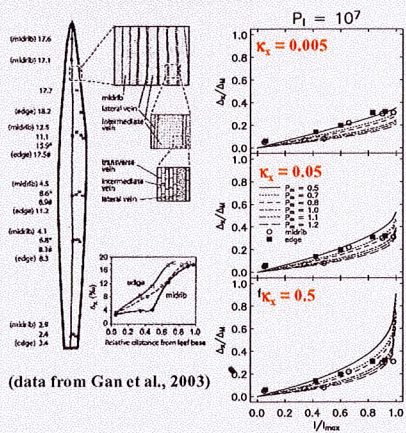
### Model equations

In leaf xylem 
$$\frac{\partial R}{\partial t} + \frac{\partial}{\partial r} \left( v_r R - D \frac{\partial R}{\partial r} \right) + \frac{1}{r} \frac{\partial}{\partial r} \left( r v_r R - r D \kappa_x \frac{\partial R}{\partial r} \right) = 0$$

In mesophyll 
$$\frac{\partial R}{\partial t} + \frac{\partial}{\partial r} \left( v_m R - D \kappa_m \frac{\partial R}{\partial r} \right) + \frac{\partial}{\partial l} \left( -D \kappa_m \frac{\partial R}{\partial l} \right) = 0$$

Boundary condition at  $r = r_x$  
$$2\pi r_x l_{max} \left( v_r R(r_x^+, l, t) - D \kappa_x \frac{\partial R}{\partial r} \right) = s l_{max} \left( v_r R(r_x^-, l, t) - D \kappa_x \frac{\partial R}{\partial r} \right)$$

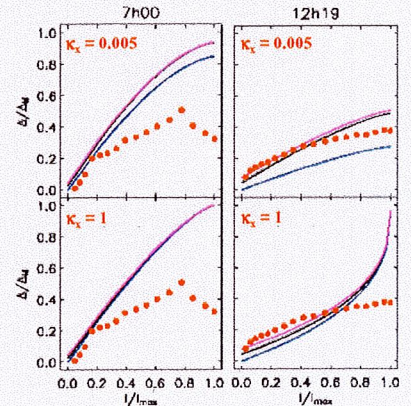
## IV. RESULTS



Accounting for a radial tortuosity factor in the leaf xylem ( $\kappa_x$ ) enables to correctly reproduce the observed progressive isotope enrichment of xylem water along a maize leaf under steady environmental conditions

In the field with a naturally varying environment, non steady-state effects seem to dominate in the morning regardless of the value of the tortuosity factor in the leaf xylem or in the leaf mesophyll

— bulk  
 — xylem  
 — mesophyll  
 — measurements } steady-state model only



## V. CONCLUSIONS & PERSPECTIVES

We think that our formulation is promising when one tries to describe the isotopic composition of leaf water and transpiration in a naturally varying environment as it allows to account for both non steady-state and diffusive effects consistently. Yet this formulation is a simplification of what happens in monocot leaves but cannot be applied other than qualitatively to coniferous needles or dicotyledonous leaves with their reticulate network of veins.

In the future we plan to 1/ explore the role of longitudinal diffusion in mesophyll, 2/ better characterize non steady-state effects, 3/ simplify the model equations for bulk leaf water in order to generalize the results to other leaf types (needles, dicotyledon leaves) and use them in terrestrial ecosystem models.

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