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A model of mechanics and gas exchange in a neighborhood of a single stoma

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Highlights: The interplay of stomatal behaviour, epidermis mechanics, water flow, and diffusion is modeled dynamically with a system of ordinary and partial differential equations based on mechanical and thermodynamic principles. Simulation results of the discretised equations are shown.

Keywords: Stomata, mechanics, turgor, diffusion, model, simulation.

To gain insight in the physics and regulation of gas exchange (water vapour, carbon dioxide, and oxygen) in plant leaves we propose a dynamical first-principle model for a small disc-shaped section of a leaf around a single stoma (see Fig. 1). We consider different layers of tissues starting from the lower surface: the lower epidermis with a perfectly impermeaple cuticule and stomata controlled by guard cells, the interstitial air space, and the photosynthetically most active tissues (spongy and palisade parenchyma cells lumped together). The upper epidermis with its cuticule is assumed to contain no stomata and is treated as impermeable. We focus on the mechanical interaction between epidermis cells and guard cells, coupled to water transport driven by water potential gradients and diffusion of solvents in the symplastic and apoplastic compartments of the epidermis, as well as evaporation into and diffusion within the interstitial air space. Vapour exchange with the ambient air is controlled by stomatal aperture which in turn is determined by the mechanics and the guard cell solute content. During opening and closing of stomata solvents are pumped between the guard cell symplast and apoplast. The underlying physical processes, along with typical parameter values are described in standard literature (e.g. Nobel, 2005).

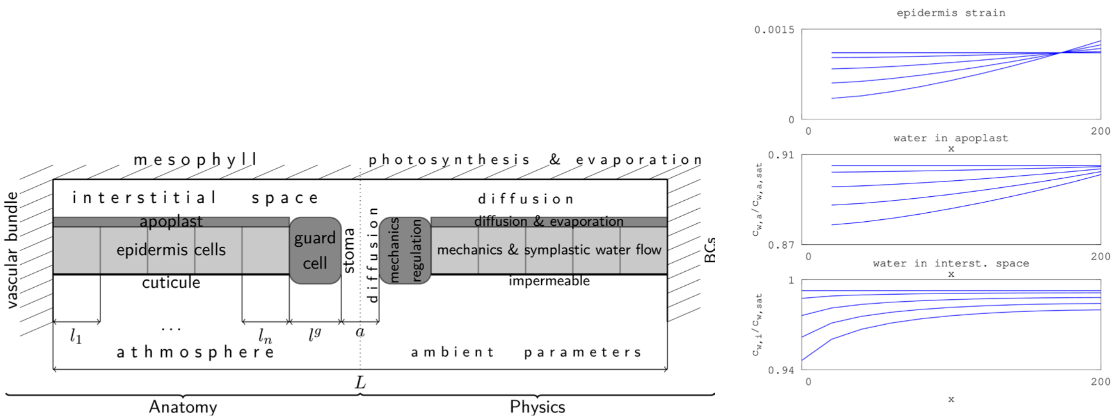

Fig. 1.a) Section through leaf centered around a single stoma b) Steady state profiles for apertures 0 – 10 µm

The structure of the resulting model is a coupled system of ordinary and parabolic partial differential equations (reaction diffusion equations). This provides a more detailed description in particular with respect to spatial resolution as compared to resistor network models. It also captures dynamic effects and links microscopic physical properties, such as known diffusion constants, to observable quanities such as stomatal aperture and net transpiration rates. It provides a physically accurate explanation to the inverse behaviour of stomatal aperture after sudden changes in ambient parameters such as ambient moisture (see Mott et al., 1997). A finite volume approach was applied for space discretisation and computational results are shown. This model is intended to serve as a building block for a more comprehensive model of the leaf.

LITERATURE CITED

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