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Remote sensing of plant-water relations: An overview and future perspectives

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ABSTRACT

Vegetation is a highly dynamic component of the Earth surface and substantially alters the water cycle. Particularly the process of oxygenic plant photosynthesis determines vegetation connecting the water and carbon cycle and causing various interactions and feedbacks across Earth spheres. While vegetation impacts the water cycle, it reacts to changing water availability via functional, biochemical and structural responses. Unravelling the resulting complex feedbacks and interactions between the plant-water system and environmental change is essential for any modelling approaches and predictions, but still insufficiently understood due to currently missing observations. We hypothesize that an appropriate cross-scale monitoring of plant-water relations can be achieved by combined observational and modelling approaches. This paper reviews suitable remote sensing approaches to assess plant-water relations ranging from pure observational to combined observational-modelling approaches. We use a combined energy balance and radiative transfer model to assess the explanatory power of pure observational approaches focussing on plant parameters to estimate plant-water relations, followed by an outline for a more effective use of remote sensing by their integration into soil-plant-atmosphere continuum (SPAC) models. We apply a mechanistic model simulating water movement in the SPAC to reveal insight into the complexity of relations between soil, plant and atmospheric parameters, and thus plant-water relations. We conclude that future research should focus on strategies combining observations and mechanistic modelling to advance our knowledge on the interplay between the plant-water system and environmental change, e.g. through plant transpiration.

1. Introduction

The soil, plants and atmosphere are connected via flows of energy and matter including water and carbon (Baldocchi et al., 2001). Plant photosynthesis and a complex set of supporting physiological processes are the driving forces of these exchange processes, including the uptake of atmospheric carbon and storage in ecosystems and the extraction of water from the soil and its release into the atmosphere (Lambers et al., 2008). Therefore, vegetation is an important and highly dynamic component of the carbon and water cycle (Reichstein et al., 2013).

Driven by soil water availability and atmospheric water demand, water is in continuous flow in the soil-plant-atmosphere continuum (SPAC) (Asbjornsen et al., 2011). However, only approximately 1% of the water extracted by plants from the soil during the growing season is actually used for plant growth; the rest is released as water vapour to the atmosphere through plant transpiration, an unavoidable by-product of carbon exchange via stomata openings (Green et al., 2017; Nobel, 2009; Reichstein et al., 2013). Evapotranspiration summarizes the water fluxes from terrestrial ecosystems to the atmosphere, and combines plant transpiration and evaporation of water from the soil and plant surfaces. In vegetated ecosystems, transpiration is, with a contribution of up to 90%, the largest component of evapotranspiration (Jasechko et al., 2013). Besides its role in water cycle dynamics, vegetation also responds to changing water availability: water is

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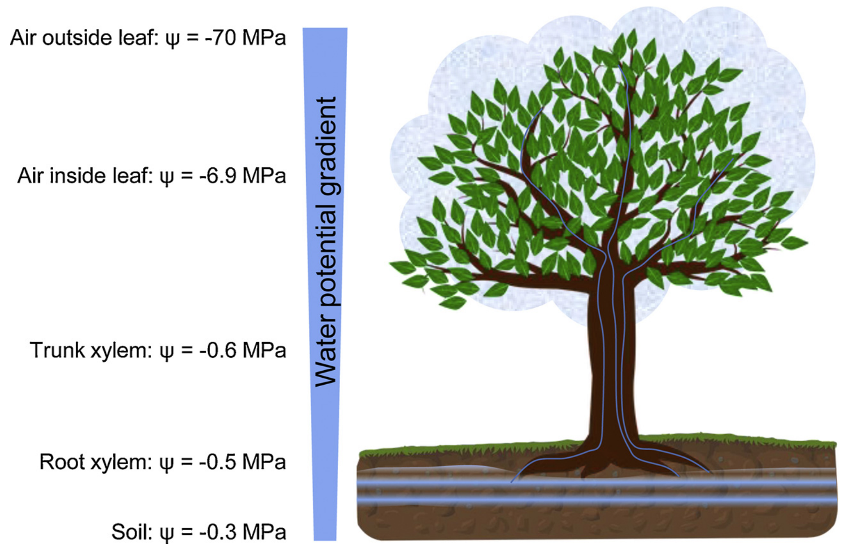

Fig. 1. Schematic drawing of water flow across the SPAC (right) including the gradient of the water potential ψ (left). Indicated water potentials represent typical values for several species according to Nobel (2009). Water potentials vary with environmental factors and might substantially differ in extreme cases.

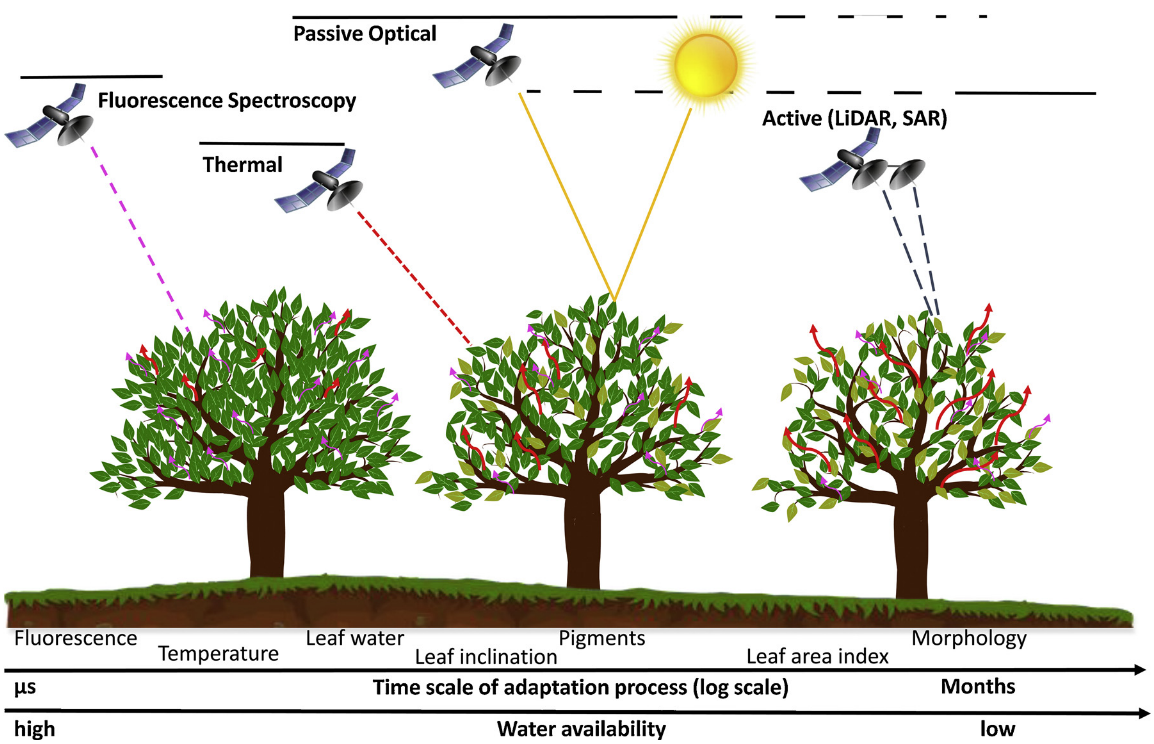

Fig. 2. Conceptual overview on the impact of plant water availability on physiological, biochemical, and structural adaptation mechanisms, and remote sensing technology sensitive to such plant adaptation mechanisms. Purple arrows indicate fluorescence radiation emitted by plants, red arrows relate to thermal radiation emission. Bold lines indicate the application spectrum of remote sensing technology, dashed lines indicate limited applicability.

embedded in cells, transports nutrients, provides structural support (turgor), supports plant movements, and stabilizes temperature. Small variations in water availability may lead to functional responses of plants (Nobel, 2009). The double role of vegetation in driving water cycle dynamics and responding to it determines vegetation ecosystems to cause several interactions and feedbacks across Earth spheres (Richardson et al., 2013; Seneviratne et al., 2010; Suni et al., 2015).

Gradients of water potentials across the SPAC provide the physical force for the uptake of soil water by the root system, the transport of water through the plant xylem to the leaves, and the release of water into the atmosphere through stomatal pores (Norman and Anderson, 2005). As a result, plant-water relations (i.e. storage and flow of water in plants) highly depend on soil water content and atmospheric water vapour deficit. Plant-water relations are thus expected to vary with environmental change (i.e. varying pattern of temperature and precipitation, increasing aerosol emissions, and atmospheric CO_2 concentrations) via complex feedback mechanisms. Increasing atmospheric CO_2 concentrations, for example, fertilize plant photosynthesis and will likely alter carbon and water exchange in vegetated ecosystems (Nobel, 2009). Observed reductions in stomata density of C3 plants with increasing CO_2 concentrations possibly lead to a decrease in transpiration rates (Lammertsma et al., 2011). Such developments could also impact plant diversity of ecosystems due to plant adaptation or shifts towards species communities more resistant to changing environmental