Measurement and Simulation of Environmental Controls on Vegetation Water Use for Selected Native Species in South Australia

BY

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To My Wife

YUNHUI GUO

And My Son

ZHIBIN WANG

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Summary

Plants need water to survive, so the distribution, structure and composition of plant communities are influenced by water availability, at the same time, plants are a major conduit for water to return to the atmosphere, and hence influence climate and exert strong effects on hydrologic fluxes in the land-atmosphere system. Ecohydrological studies typically focus on the understanding of the interactions between hydrologic and ecosystem processes, and how these processes are manifested across spatiotemporal scales. In recent years, ecohydrologists have increased emphasis on understanding the plant-water relations, especially the vegetation water use and mechanisms controlling the responses to environmental conditions. Understanding the species-specific patterns of plant water use and the connections with atmospheric conditions is useful for improving land and water management through afforestation/deforestation efforts. In this context, this thesis focuses on the vegetation water use (interchangeable with transpiration, E_c) of selected native species in South Australia and the responses to a series of environmental variables, including air temperature, vapour pressure deficit, solar radiation and soil water condition which is reflected by either plant stem water potential or the most commonly used volumetric soil water content. Some of the main issues in current ecohydrological studies are explored in this thesis, for example, the upscaling of water fluxes from the tree scale to stand or catchment scale, the transferability of information across temporal and spatial scales, and the effects of heterogeneity and complexity of land surface on vegetation water use and the responses to environmental conditions. Specifically, the following five projects have been conducted to form this thesis.

Transpiration (E_c) is often simulated in land surface models based on the relationship with environmental variables. According to the structure of E_c models, they can be categorized into ″direct″ and ″indirect″ ones. The latter refers mainly to the Penman-Monteith equation, with g_c correlated to environmental variables; while the former simulates E_c straightforward using environmental variables, omitting the calculation of g_c. Most g_c models are empirically developed by establishing relationship between g_c and different environmental variables; therefore, the g_c models and relevant parameters are highly site specific, i.e. the response functions and parameter values may change with species and climate conditions. The first part of this thesis is focused on species-specific model selections. An appropriate g_c model for one Australian native species Drooping Sheoak was determined by running an optimization model. In the meantime, the significance of temperature functions for canopy conductance modelling, which is often neglected in previous studies, was tested.

Once the appropriate g_c model was determined, in the second part of this thesis, it was applied in the ″indirect″ method for E_c modelling, and the simulation results were compared to two types of ″direct″ models, to determine which category of E_c models better reproduced sap flow measurement. Moreover, the environmental conditions that constrain tree water use can be divided into supply and demand variables. Soil water condition is the only supply variable that has been widely discussed. Transpiration from trees that grow at riparian sites and from trees that access groundwater is not limited by soil water condition. Rainfall influence soil water dynamics, and therefore tree water uptake differs among seasons accordingly. Therefore, whether and when soil water condition function has significant influence on tree water use simulations were determined by comparing the ″direct″ and ″indirect″ models at daily and hourly scales; and the transferability of parameterization across temporal scales was also discussed.

For water balance studies using sap flow techniques, the upscaling of sap flux from individual trees to forest or catchment scale transpiration is particularly important. The scaling issue is one of the most important research questions in ecohydrological studies. Sapwood area is the most common scalar to accomplish this, thus it is realized that quantification of sapwood area is crucial for accurate transpiration estimation. In the third part of this thesis, a recent developed geophysics based technique, electrical resistivity tomography (ERT), was applied to estimate sapwood width. Compared to incremental wood cores ERT is relatively non-destructive and efficient. ERT not only gives point estimation of sapwood width, but also provides spatial variation of sapwood sections, which is useful for sensor positioning at the beginning of sap flow measurements.

Complex terrain brings forth more challenges in understanding the plant-water relations, because terrain conditions lead to the variability of solar energy, soil water and microclimate, and hence further influence the tree growth and distribution. In the fourth part of this thesis, field measurements were presented for comparison of tree water use, micrometeorological conditions, and soil water dynamics on two slopes with contrasting aspects (north facing vs. south facing) in a small native forest stand in South Australia, in order to examine plant-water relations mediated by topography. Comparison among daily soil water content, transpiration and potential *ET* indicates that tree water use at the site was mainly controlled by soil water supply in summer and autumn and by evaporative demand in winter and spring. The total estimated transpiration in the study period was similar on both slopes, although difference was observed during dry and wet periods. The response of tree water use to vapour pressure deficit and solar radiation was similar on both slopes; the response to soil water content was slightly different. Trees on north facing slope suffered water stress longer than trees on the other slope.

Studies at a point or catchment scale provide important knowledge of the plant-water relations; they reveal how vegetation is influenced by and influences the local climate conditions through water and energy exchanges. However, water resource management usually requires the knowledge and the quantification of water components more importantly at regional scale. For large spatial scale water component estimation ground measurements are limited in spatial representativeness, temporal continuity, and the extrapolation from point measurements to large area quantity has big uncertainties. Satellite observations overcome some of these limitations of field measurement. Therefore, in the last part of this thesis, water budget was examined over continental Australia using data obtained from different satellite platforms, that is, rainfall from Tropical Rainfall Measuring Mission (TRMM), evapotranspiration from Moderate Resolution Imaging Spectroradiometer (MODIS), and water storage change from the Gravity Recovery and Climate Experiment (GRACE). Water budget was examined in rainfall-limited and runoff-limited regions of Australia, and particularly an internal drainage basin, Lake Eyre Basin. Application of the satellite products for the water balance study in Lake Eyre Basin reflects well the seasonal hydrological processes in terms of net groundwater flow, and gives a reasonable estimation of the maximum possible integrated error of the three products as well as the maximum net groundwater inflow to the basin. This part using remote sensing data on a much larger spatial scale than the previous sections does not contribute to the core of the thesis, so the study is attached as an appendix in the end.

Declaration of Originality

I certify that this thesis does not incorporate, without acknowledgment, any material previously submitted for a degree or diploma in any other university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Hailong Wang

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By three methods we may learn wisdom: first, by reflection, which is noblest; second, by imitation, which is easiest; and third by experience, which is the bitterest.

Confucius (551-479 B.C.)

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