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Research papers

Soil-water content characterisation in a *modified Jarvis-Stewart* model: A case study of a conifer forest on a shallow unconfined aquifer

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ABSTRACT

Groundwater-vegetation-atmosphere fluxes were monitored for a subtropical coastal conifer forest in South-East Queensland, Australia. Observations were used to quantify seasonal changes in transpiration rates with respect to temporal fluctuations of the local water table depth. The applicability of a *Modified Jarvis-Stewart* transpiration model (MJS), which requires soil-water content data, was assessed for this system. The influence of single depth values compared to use of vertically averaged soil-water content data on MJS-modelled transpiration was assessed over both a wet and a dry season, where the water table depth varied from the surface to a depth of 1.4 m below the surface.

Data for tree transpiration rates relative to water table depth showed that trees transpire when the water table was above a threshold depth of 0.8 m below the ground surface (water availability is non-limiting). When the water table reached the ground surface (*i.e.*, surface flooding) transpiration was found to be limited. When the water table is below this threshold depth, a linear relationship between water table depth and the transpiration rate was observed. MJS modelling results show that the influence of different choices for soil-water content on transpiration predictions was insignificant in the wet season. However, during the dry season, inclusion of deeper soil-water content data improved the model performance (except for days after isolated rainfall events, here a shallower soil-water representation was better). This study demonstrated that, to improve MJS simulation results, appropriate selection of soil water measurement depths based on the dynamic behaviour of soil water profiles through the root zone was required in a shallow unconfined aquifer system.

1. Introduction

Tree transpiration is a significant component of the hydrological cycle in forest systems and as such its quantification and forecasting is important for the development of robust, defensible and sustainable water management strategies (Schlesinger and Jasechko, 2014). The four environmental variables that are the primary drivers of transpiration are solar radiation, vapour pressure deficit, soil moisture and leaf area index (Jarvis, 1976; Harris et al., 2004; Asbjornsen et al., 2011; Whitley et al., 2013). Transpiration can be modelled using either physical or empirical analyses of these variables. Potential evapotranspiration is often calculated by the physically-based Penman-Monteith (PM) equation (1965). Building on the PM equation, Jarvis (1976) and later Stewart (1988) further describe the stomatal (or canopy) conductance using an empirical approach, which are usually named as a *Jarvis-* or *Jarvis-Stewart*-type model (see Table 1). This approach allows an estimate of canopy water flux for a site under specific meteorological conditions using the PM equation, without requiring field data of canopy conductance. Recently, empirical approaches were developed to quantify transpiration directly, circumventing the need for canopy conductance data (Whitley et al., 2008, 2009, 2013), and this approach is termed the "modified *Jarvis-Stewart* model".

All of these empirical models assume that soil-water content is a key variable for accurate simulation of transpiration (see Table 1; Granier and Loustau (1994), Harris et al. (2004), Liu et al. (2009), etc.). In practice, the calibration of the soil-water content function

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Table 1
Summary of relevant studies performing transpiration or canopy conductance modelling based on empirical approaches.

Study	Model used	Input data	Target data	Location	Vegetation type, tree density	Key results	Soil-water content characterisation
Stewart (1988)	Jarvis-Stewart	R_s, D_0, T, SWC	g_c (derived from BREB)	Thetford Forest, UK	*Pinus Sylvestris* (L.) and *Pinus nigra var. maritima* (Ait.), 619 trees ha^{-1}	Non-linear functions including SWC are best to predict g_c	SWC recorded every few days using a Neutron probe at 0.2, 0.35, 0.5, 0.8 and 1.1 m and integrated over the profile
Granier and Loustau (1994)	Jarvis-type	R_s, D_0, SWC	g_c (derived from SF)	Landes, Southwest France	*Pinus pinaster* (Ait.) of different ages and densities (see Granier and Loustau (1994) for details)	Inclusion of SWC function in Jarvis-type model. Importance of accurate determination of SWC and stand leaf area	SWC measured using a Neutron probe at 10 days intervals
Sommer et al. (2002)	MLR, Jarvis-type	R_n, T, VPD, D_0	g_c (derived from BREB)	Eastern Amazon, Brazil	Fallow vegetation; Biomass of 22.2 t DM ha^{-1}	MLR outperforms Jarvis-Type models. SWC has to be included in further Jarvis-Type studies	No SWC included in the modelling
Harris et al. (2004)	Jarvis-Type	R_n, T, D, SWC	g_c (derived from EC)	Manaus, Brazil	Amazonian rainforest, Biomass 300–350 t ha^{-1}	Inclusion of a SWC function in Jarvis-type model improved the g_c predictions	SWC measured weekly over the top 3.8 m
Whitley et al. (2008, 2009)	MJS (+ PM and ANN for Whitley et al. (2009))	R_n, VPD, SWC, LAI	T (derived from SF)	Northwestern NSW, Australia	*Eucalyptus crebra* (42 trees ha^{-1}) and *Callitris glaucophylla* (212 trees ha^{-1}) (see Zeppel and Eamus (2008) for details)	MJS performs better than PM for low SWC	SWC measured at 50 cm depth below surface
Liu et al. (2009)	ANN, MLR	VPD, R_n, T, u, SWC, LAI	T (derived from SF)	Wuwei, Gansu Province, China	Plantation of *Pyrus pyrifolia cv. Pingguoli* (500 trees ha^{-1})	ANN superior to MLR for predicting SF. SWC a key variable for the performance of the ANN	SWC measured at 5–10 days intervals and integrated over 1 m
García-Santos et al. (2009)	Jarvis-Stewart	R_s, D_0, T, SWC	g_c (derived from SF)	Canary Island, Spain	*M. Faya* (57%), *E. arborea* (33%), *L. azorica* (10%) 1266 trees ha^{-1}	SWC had little influence on g_c even during dry periods. Authors hypothesise deep rooting systems	SWC recorded at 15-min intervals at 0.15 and 0.3 m below surface and averaged
Whitley et al. (2013)	MJS, ANN	R_n, VPD, SWC, LAI	T (derived from SF)	Five Australian ecosystems	See Whitley et al. (2013) for details	Site specific versus combined site model calibration shows that combined site calibration works well. SWC function optimization remains site-specific	SWC function defined based on permanent and wilting point (according to soil type)

MJS: Modified Jarvis Stewart, ANN: Artificial Neural Network, PM: Penman-Monteith, MLR: Multiple Linear Regression, GLM: General Linear Model; SF: Sapflow; BREB: Bowen Ratio energy balance; EC: Eddy covariance. E_0, potential evapotranspiration; RH, Relative Humidity; R_s: Solar radiation; R_n: Net radiation, T: Air temperature; u: wind speed at 2 m; D_0: Specific humidity; g_c: Canopy conductance; LAI: Leaf Area Index.