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Root-zone "Periscope": Modelling plant-available water storage dynamics across scales from aboveground observations

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Abstract: Estimation of root-zone water storage is critical for predicting catchment rainfall-runoff response and ecosystem drought response to improve water, forest, and agricultural management under changing climates. However, estimating root-zone water storage even at the individual-plant scale remains challenging due to the soil heterogeneity and the difficulty in delineating the root-zone extent. In this study, we propose a Root-zone "Periscope" framework that uses aboveground observations of plant water potential and sap flow to infer below-ground root-zone water storage dynamics, an upside-down analogue of a periscope in submarine. The Root-zone Periscope (RZP) framework builds on new conceptualisation of the root zone, including the Root-Zone Water Storage Release Curve (RZWRC) which describes the relationship between representative root-zone water potential and root-zone water storage, and the root-zone specific yield which is the derivative of RZWRC. Once RZWRC is determined, the root-zone water storage capacity ($S_{r,max}$) and its dynamics (S_r) can be derived from aboveground plant water potential measurement. We tested the RZP framework in greenhouse experiments on several golden wattle (*Acacia pycnantha*) trees, which confirmed the validity of the RZWRC and the feasibility of using the root zone specific yield method to obtain $S_{r,max}$ and S_r on the individual tree scale. We then applied the method in field conditions and successfully estimated S_r for individual drooping sheoak (*Allocasuarina verticillata*) trees. Built on this foundation, the RZP framework has been extended to the ecosystem scale by using plant water potential inferred from satellite observations and evapotranspiration data from flux towers. We tested this large-scale application based on the AmeriFlux site US-Me2 (Metolius mature pine forest, Oregon, USA), where forest water potential was inferred from vegetation optical depth (VOD) and NDVI. The RZP framework estimated monthly root-zone water storage dynamics over 20 years. The result revealed a significant depletion in root-zone water storage from 2000 to 2020 due to vegetation overgrowth following a wet episode in late 1990s. This overgrowth-induced root-zone moisture depletion explains a sharp decrease of net ecosystem production in late 2010s and a wildfire in 2020. A similar relationship between precipitation decadal variability and root-zone moisture and bushfire dynamics has been reported in Australia. These studies demonstrate a scalable approach for estimating root-zone water storage capacity and dynamics from greenhouse to stand level. The RZP framework provides a novel way to parameterize root-zone water storage in land-surface models and to assess ecosystem ecohydrological processes and water-carbon coupling, offering new opportunities for water resource and forest management and climate adaptation.

Keywords: *Root zone water storage, water potential, sap flow, vegetation optical depth, NDVI*