Automated parameterization of stomatal conductance models from thermal imagery by leveraging synthetic images generated from Helios 3D biophysical model simulations

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Abstract

Stomatal conductance (g_s) is a critical plant biophysical variable that reflects plant regulation of CO_2 uptake and associated water loss, yet its direct measurement is often prohibitively time-consuming. Estimating the impacts of g_s indirectly through leaf temperature (T_{leaf}) is a common practice, but is complicated by confounding factors such as ambient conditions, measurement aggregation scale, sample size, and measurement time. Using T_{leaf} measurements to instead determine parameters of a model for g_s that can remove these external factors can provide quasi-traits that are more reliable and heritable. Our objective was to develop an automated pipeline for g_s model parameterization using thermal data, which could be applied within a 3D biophysical model to predict the impacts of trait variation on canopy-level processes related to water-use efficiency. Field experiments were conducted on common bean, cowpea, and sorghum crops, involving high-resolution thermal measurements obtained from a robotic sensing platform. Subsequently, a deep learning algorithm was trained using synthetic thermography data generated using Helios 3D model simulations encompassing canopy structure, ambient conditions, and T_{leaf}, enabling the prediction of long-wave radiation and incident shortwave radiation for each thermal image pixel. Following this, a leaf-surface energy budget analysis was applied to the collected field thermal data to predict g_s parameters. Validation of these predictions was performed through comparisons with ground-truth leaf-level gas exchange data. This pipeline offers a promising pathway to predictive simulations of water status and transpiration-related traits, regardless of environmental variation, ultimately enhancing our understanding of plant responses to changing environmental conditions.

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