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Research paper

Incorporating non-stomatal limitation improves the performance of leaf and canopy models at high vapour pressure deficit

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Vapour pressure deficit (*D*) is projected to increase in the future as temperature rises. In response to increased *D*, stomatal conductance (g_s) and photosynthesis (*A*) are reduced, which may result in significant reductions in terrestrial carbon, water and energy fluxes. It is thus important for gas exchange models to capture the observed responses of g_s and *A* with increasing *D*. We tested a series of coupled A–g_s models against leaf gas exchange measurements from the Cumberland Plain Woodland (Australia), where *D* regularly exceeds 2 kPa and can reach 8 kPa in summer. Two commonly used A–g_s models were not able to capture the observed decrease in *A* and g_s with increasing *D* at the leaf scale. To explain this decrease in *A* and g_s, two alternative hypotheses were tested: hydraulic limitation (i.e., plants reduce g_s and/or *A* due to insufficient water supply) and non-stomatal limitation (i.e., downregulation of photosynthetic capacity). We found that the model that incorporated a non-stomatal limitation captured the observations with high fidelity and required the fewest number of parameters. Whilst the model incorporating hydraulic limitation captured the observed *A* and g_s, it did so via a physical mechanism that is incorrect. We then incorporated a non-stomatal limitation into the stand model, MAESPA, to examine its impact on canopy transpiration and gross primary production. Accounting for a non-stomatal limitation reduced the predicted transpiration by ∼19%, improving the correspondence with sap flow measurements, and gross primary production by ∼14%. Given the projected global increases in *D* associated with future warming, these findings suggest that models may need to incorporate non-stomatal limitation to accurately simulate *A* and g_s in the future with high *D*. Further data on non-stomatal limitation at high *D* should be a priority, in order to determine the generality of our results and develop a widely applicable model.

Keywords: hydraulic limitation, model-data assimilation, photosynthesis, stomatal conductance.

Introduction

Vapour pressure deficit (*D*) is the difference between the amount of water vapour that the air can hold at saturation (e_s) and the actual amount of water vapour in the air (e_a; Monteith and Unsworth 2013). With rising air temperature, e_s increases exponentially and as a result *D* is projected to increase strongly in the future (Ficklin and Novick 2017). At the leaf level, as *D* increases and plant water supply becomes limiting, a direct reduction in stomatal conductance (g_s) occurs to limit transpiration, which inevitably also affects photosynthesis (*A*; Cowan and Farquhar 1977). The reduction of *A* and potentially transpiration due to increasing *D* has important implications for global carbon-climate predictions (Reichstein et al. 2013, Will et al. 2013). Thus, it is crucial to understand the response of vegetation to the projected increase in *D* (Novick et al. 2016).