Physically-based simulation of plant hydraulic transport and drought stress in Australian vegetation

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Abstract: Drought impacts on ecosystem health are likely to amplify in a warming world, especially in the many regions where reduced rainfall is also projected. To manage these increasing risks, we need vegetation models that can accurately simulate plant water stress and mortality. Mechanistic plant hydraulics modules are becoming increasingly popular because they simulate the movement of water through the soil-plant-atmosphere continuum based on water potential gradients, which aligns with the underlying physics of plant water use. Such modules have been coupled to several leading vegetation modules, applying a variety of methods and assumptions. However, existing modules suffer from limitations including poor computational efficiency and unreasonable results under extreme conditions, partly because different processes govern plant behaviour at varying levels of water stress.

We developed a new plant hydraulics module, coupled to a modified version of the vegetation demography model LPJ-GUESS, that overcomes both limitations by automatically switching between 'low water stress' and 'high water stress' modes depending on the conditions. The first mode is relevant any time the stomata are fully or partly open. It simulates root water uptake based on both root density and soil water content within the 15 soil layers. Stomatal regulation of transpiration responds to changing vapour pressure deficit and soil water content, and plant water stress is estimated with reference to measured xylem vulnerability traits. The combination of a well-tested stomatal conductance model and a physically based approach to simulating plant water stress through xylem water potential is a key advantage of our approach.

The second mode is used under high water stress, when stomata are fully closed and root water uptake is assumed negligible due to low soil hydraulic conductivity. We avoid substantial model complexity by fixing stomatal conductance at its minimum (cuticular conductance) and allowing the vegetation to access its internal water stores only. The model simulates depletion of these stores until xylem damage and eventually mortality occur. Water stressed plants switch back to their original non-water stressed state following rain (i.e. back to the first mode). Vegetation that has experienced drought stress is subsequently modelled with lower sapwood conductance, accounting for the loss of capacity due to xylem embolism. Conductance gradually recovers in line with sapwood turnover.

We parameterised and validated the model at Cumberland Plain, a eucalypt-dominated site where ecosystem-scale carbon and water flux measurements are available. Without substantially increasing the computational cost, the model with the new plant hydraulics module reasonably replicated leaf area (Figure 1a) along with water and carbon fluxes (Figure 1b-d). Future work will apply the module at sites where vegetation experienced xylem damage and mortality in the 2018/19 drought. This model upgrade offers the opportunity to better understand and manage future drought risk to ecosystems.

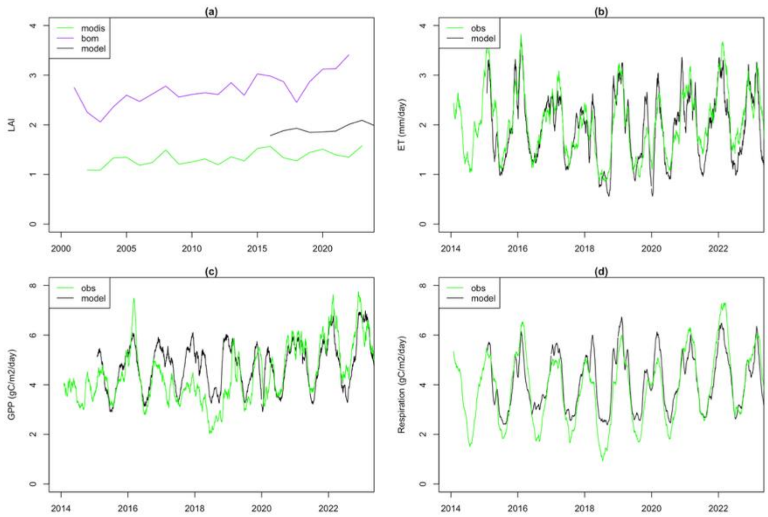

Figure 1 Preliminary model results at Cumberland Plain

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