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Mesophyll conductance controls over ecophysiological responses to drought in 6 Mediterranean forest ecosystems – Data analysis and modelling

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Projections of climate change suggest that higher temperatures, and increased potential evapotranspiration, together with changes in seasonal precipitation patterns, will work to reduce the soil water available for terrestrial vegetation, possibly leading to an increase in global drought events. Water availability is currently the biggest global limiting factor to photosynthesis, and a reduction in available soil water could potentially cause a large feedback effect on the climate system in the future, by further limiting photosynthesis in certain regions. The effect of water stress on ecosystem function is not well understood. In particular, little agreement exists on which are the controlling mechanisms behind plant photosynthetic responses to water stress. This leads to big discrepancies when modelling in these conditions, as has been highlighted by modelling attempts in Mediterranean ecosystems, which typically suffer seasonal annual water stress.

In the presented work, we investigate photosynthetic water stress control mechanisms, their timing and extent on the canopy scale in real world conditions. Twenty years of half hourly FLUXNET data, gathered at six Mediterranean forest sites made it possible to separate stomatal conductance, mesophyll conductance and biological limitations to assimilation. Three sites in Mediterranean Europe (Puéchabon, France; Roccarespampani, Italy; Collelongo, Italy), one site in Israel (Yatir) and two sites in the United States (Blodgett & Tonzi, California) were chosen, covering 6 dominant

Mediterranean species, over a wide range of environmental conditions.

Stomatal and mesophyll conductance are calculated from the FLUXNET data, using the Ball, Berry & Luening, and Harley conductance models. Their responses, and the resulting changes in leaf intercellular and chloroplast carbon concentrations, to changes in soil water availability are thus assessed. A quantitative analysis was employed to gauge their relative roles, and that of biochemical limitations, in the control of photosynthesis. A process based biogeochemical model was then used to test the suggestion that non-stomatal limitations could, and should, be simulated though the inclusion of a mesophyll conductance sub-model. The effectiveness of calculating photosynthesis based on carbon in the chloroplast, instead of that in the intercellular spaces, is assessed.

The results give a detailed look at how forest carbon and water balances are affected by water stress, and improve our understanding of the effect of soil water stress on photosynthesis. They show that the currently accepted hypothesis of stomatal sole control over photosynthesis does not hold in water stressed conditions, and reveal the involvement of limitations to net photosynthesis, attributable to finite mesophyll conductance, which come into play under more severe water stress. It is shown that, applying non-stomatal limitations to assimilation through a finite and responsive mesophyll conductance, carbon and water fluxes can now for the first time be modelled, based on the underlying processes, to an equal degree of accuracy in both wet and dry conditions.