Biogeosciences, 17, 265–279, 2020
https://doi.org/10.5194/bg-17-265-2020

Biogeosciences Open Access EGU

Low sensitivity of gross primary production to elevated CO_2 in a mature eucalypt woodland

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Received: 5 July 2019 – Discussion started: 31 July 2019
Revised: 3 December 2019 – Accepted: 5 December 2019 – Published: 20 January 2020

Abstract. The response of mature forest ecosystems to a rising atmospheric carbon dioxide concentration (C_a) is a major uncertainty in projecting the future trajectory of the Earth's climate. Although leaf-level net photosynthesis is typically stimulated by exposure to elevated C_a (eC_a), it is unclear how this stimulation translates into carbon cycle responses at the ecosystem scale. Here we estimate a key component of the carbon cycle, the gross primary productivity (GPP), of a mature native eucalypt forest exposed to free-air CO_2 enrichment (the EucFACE experiment). In this experiment, light-saturated leaf photosynthesis increased by 19 % in response to a 38 % increase in C_a. We used the process-based forest canopy model, MAESPA, to upscale these leaf-level measurements of photosynthesis with canopy structure to estimate the GPP and its response to eC_a. We assessed the direct impact of eC_a, as well as the indirect effect of photosynthetic acclimation to eC_a and variability among treatment plots using different model scenarios.

At the canopy scale, MAESPA estimated a GPP of $1574\,g\,C\,m^{-2}\,yr^{-1}$ under ambient conditions across 4 years and a direct increase in the GPP of +11 % in response to eC_a. The smaller canopy-scale response simulated by the model, as compared with the leaf-level response, could be attributed to the prevalence of RuBP regeneration limitation of leaf photosynthesis within the canopy. Photosynthetic acclimation reduced this estimated response to 10 %. After taking the baseline variability in the leaf area index across plots in account, we estimated a field GPP response to eC_a of 6 % with a 95 % confidence interval (−2 %, 14 %). These findings highlight that the GPP response of mature forests to eC_a is likely to be considerably lower than the response of light-saturated leaf photosynthesis. Our results provide an important context for interpreting the eC_a responses of other components of the ecosystem carbon cycle.

1 Introduction

Forests represent the largest long-term terrestrial carbon storage (Bonan, 2008; Pan et al., 2011). The atmospheric carbon dioxide concentration (C_a) has increased significantly since the beginning of the industrial era (Joos and Spahni, 2008), but the increase would have been considerably larger without forest carbon sequestration, which is estimated to have offset 25 %–33 % of recent anthropogenic CO_2 emissions (Le Quéré et al., 2018). C_a is projected to continue to increase by 1–5 $\mu mol\,mol^{-1}\,yr^{-1}$ into the future (IPCC, 2014), but the rate of this rise depends on the magnitude of the forest feedback on C_a. At the leaf scale, the direct physiological effects of rising C_a are well understood: elevated C_a (eC_a) stimulates plant photosynthesis (Kimball et al., 1993; Ellsworth et al., 2012) and reduces stomatal conductance (Morison, 1985; Saxe et al., 1998), which together increase leaf water-use efficiency (De Kauwe et al., 2014). These physiological re-