Roles of photosynthetic, respiratory, stomatal and phenological acclimation in controlling carbon and water fluxes of mature Norway spruce in a changing climate

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Boreal regions are undergoing rapid climate change but our understanding of the long-term consequences for forest processes is hampered by limited knowledge of how trees acclimate to rising atmospheric CO₂ concentrations and temperature. This study used the detailed canopy flux model MAESTRA to simulate the effects of elevated CO₂ (eCO₂) and warming on net photosynthesis ($A_n$) and transpiration ($E$) of mature boreal Norway spruce, investigating how these effects are influenced by the observed acclimation of photosynthetic capacity, respiration, stomatal behavior, and phenology. Without any type of acclimation, eCO₂ increased shoot and crown $A_n$ during the non-frost growing season by 23-44%, while warming only had a minor effect (±2%). Photosynthetic downregulation greatly decreased the positive effect under eCO₂. Under warming, both stomatal and phenological acclimation had substantial effects on $A_n$ but in opposite directions. Transpiration at shoot and crown level was greatly decreased (23-50%) by eCO₂ and increased by warming (27-42%) in the absence of acclimation. However, both these effects were largely cancelled by stomatal acclimation. Effects of eCO₂ on $A_n$ were generally smaller at entire crown compared to shoot level, as a result of photosynthetic stimulation being smaller in shaded canopy positions. In addition, upregulation of respiration in eCO₂ had a considerably larger negative effect on $A_n$ at crown compared to shoot level. Overall, tree physiological acclimation generally acted to dampen non-acclimated responses. We conclude that photosynthetic and respiratory acclimation greatly reduce the positive effect of eCO₂ on tree CO₂ assimilation, while stomatal and phenological acclimation are crucial for annual water consumption under warming. These results highlight the critical need to account for acclimation in models.