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Improved water use efficiency significantly contributes to increased primary productivity in a coupled climate-land biosphere simulation under elevated CO_2

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INTRODUCTION

One of the large uncertainties in projections of future climate is the development of atmospheric CO_2 (Denman et al, 2007). This development will depend very much on the allocation behaviour of plants under rising CO_2 conditions, i.e. on the strength of the so called CO_2 fertilization. CO_2 fertilization acts during photosynthesis primarily by more efficient carboxylation due to reduced photorespiration at elevated CO_2. Besides this direct effect, there is also an indirect one arising as a consequence of increased water use efficiency at enhanced CO_2 levels: Plants typically react with a closure of stomata, leading to a reduction in stomatal conductance by 20-50% for CO_2 doubling (Körner et al. 2007). Thereby, under suitable boundary layer conditions, canopy transpiration is less and soil water content is higher than in the non CO_2-enriched situation. Thus, water availability during the growth season is improved, and the growth season itself may be prolonged. Accordingly, the potential gain in carbon allocation from this indirect effect of CO_2-fertilization should be most expressed under semi-arid conditions. And indeed, for grasslands an inverse relationship between precipitation in the growing season and biomass gain from enhanced CO_2 could be clearly demonstrated (Morgan et al. 2004).

Climate-carbon cycle simulations of the 21st century have been criticised because of an exaggerated productivity of the land biosphere as compared to results from Free Air CO_2 Enrichment (FACE) experiments. E.g. for a doubling of atmospheric CO_2 (with respect to preindustrial level), in the Coupled Carbon Cycle - Climate Model Intercomparison Project (C4MIP) an average enhancement of net primary productivity (NPP) by about 24% was found (range: 6-33%), in contrast to 12-23% found in FACE experiments (Denman et al. 2007). We argue that this critique ignores a fundamental difference between local CO_2-enrichment and worldwide CO_2 increase: Worldwide CO_2 increase is expected to cause large scale changes in the soil-water budget due to enhanced water use efficiency of plants under elevated CO_2. FACE experiments arguably underestimate the consequences of such large scale changes because of their highly local character in an otherwise unchanged surrounding.

METHOD

To estimate the importance of such large scale changes in the soil-water budget for the productivity of the land biosphere we performed global simulations with the land biosphere model JSBACH (Raddatz et al. 2007) coupled to the atmosphere model ECHAM5 (Roeckner et al. 2003) at recent (380 ppm) and elevated (760 ppm) atmospheric CO_2 concentrations. In our simulations CO_2 acts only on the plants, and thereby indirectly through stomata also on the water cycle, but not on the radiation balance of the atmosphere, so that the climate is almost identical for both CO_2 values. The simulation setup is such that we can separate direct (reduced photorespiration) and indirect (changes in soil water budget) contributions to overall CO_2-fertilization.

RESULTS

Most prominent is the CO_2-fertilization in the equatorial zone, where under the wet conditions of the tropics the direct contribution dominates. The peaks in the indirect contributions at about 15° North and around 20° South can be attributed to dry grasslands. Overall, we find that the indirect contributions via increased soil water availability causes about 30% of the global increase in productivity from CO_2-fertilization. This surprisingly large indirect contribution, that can be expected to show up only partially in FACE experiments, may explain the discrepancy that led to the above mentioned critique of climate-carbon cycle simulations.

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