CO_2-induced greening reduces streamflow in water-stressed climates in Australia

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Abstract: Global environmental change has implications for the spatial and temporal distribution of water resources, but quantifying its effects remains a challenge. The impact of vegetation responses to increasing atmospheric CO_2 concentration on the hydrological cycle is particularly poorly constrained. CO_2-induced structural and physiological changes in vegetation potentially have consequences for water resources. CO_2 fertilization and associated greening should tend to increase vegetation water consumption by increasing the amount of transpiring leaf area, whereas reduced stomatal conductance should tend to decrease transpiration per unit leaf area – two effects with opposing consequences for streamflow. The CO_2 effect is commonly expected to manifest most strongly in water-limited environments, where moisture is the main limitation on plant growth. However, not all studies show a strong link between aridity and the strength of the CO_2 effect and the magnitude of associated greening and water savings are generally not well constrained across species and ecosystems.

We combine remotely sensed normalized difference vegetation index (NDVI) data and long-term water-balance evapotranspiration (ET) measurements from 190 unregulated, unimpaired river basins across Australia. To analyse whether the effects of rising CO_2 on vegetation and hydrology are detectable at the river basin scale, we calculated CO_2 sensitivity coefficients for NDVI and ET across basins grouped into four aridity categories (wet, sub-humid, semi-arid and arid) with the expectation that the CO_2 effect might vary systematically with aridity. In basins where the CO_2 fertilization effect dominates over the stomatal closure effect, the sensitivity of ET to CO_2 is expected to be positive. Where the stomatal closure effect dominates, the sensitivity of ET to CO_2 is expected to be negative. The sensitivity coefficients could then be used to calculate absolute changes in NDVI and ET due to CO_2 increase.

We show that sub-humid and semi-arid basins are not only 'greening' in response to increased atmospheric CO_2 but also consuming more water (marked by significant positive ET and NDVI CO_2 sensitivities). The CO_2-induced ET increases during this time period amount to 43 mm in sub-humid and 14 mm in semi-arid basins, on average. These translate to 6% and 2% increases, respectively, in mean annual ET during 1982-2010, leading to significant (24–28%) reductions in streamflow (factoring out precipitation effects). In contrast, wet and arid basins show small, non-significant changes in NDVI and reductions in ET and it was thus not possible to determine a CO_2 effect on streamflow in either the wettest or the driest regions on the basis of our measurements. Our results suggest that projected future decreases in precipitation will likely be compounded by increased vegetation water use in sub-humid and semi-arid climates, thus adding to the pressure on water resources in water-stressed regions.

Keywords: *CO_2 effect, evapotranspiration, streamflow, Normalised Difference Vegetation Index*