EGU22-7273
https://doi.org/10.5194/egusphere-egu22-7273
EGU General Assembly 2022

Emergence of the physiological effects of increasing CO_2 in the land-atmosphere exchange of carbon and water

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Increasing atmospheric CO_2 concentration influences the carbon assimilation rate of plants and stomatal conductance, and consequently affects the global cycles of carbon and water. However, the extent to which these physiological effects of increasing CO_2 significantly alters the land-atmosphere exchange of carbon and water is unclear.

To address this issue, we apply a comprehensive process-based land surface model QUINCY (QUantifying Interactions between terrestrial Nutrient CYcles and the climate system) to study the propagation of effects of increasing atmospheric CO_2 concentrations into the carbon and water cycles. We analyze century-long simulations using factorial combinations of historical forcings for representative ecosystems across different climate regimes and biomes. We develop a statistical method based on the signal-to-noise ratio to detect the emergence of the increasing CO_2 effects. We find that the signal in gross primary production (GPP) emerges at relatively small CO_2 increase ($\Delta[CO_2]$ ~ 20 ppm) since the starting point of the time period (i.e., 1901), especially at sites where the leaf area index (LAI) is relatively high. The CO_2 signal in the transpiration water flux (normalized to evaporative leaf area) emerges only at relatively high CO_2 increase ($\Delta[CO_2]$ >> 40 ppm), rooted in its high sensitivity to climate variability. In general, the increasing CO_2 effect is stronger when plant productivity is not strongly limited by climatic constraints, stronger in forest-dominated rather than in grass-dominated ecosystems. The water cycle is less susceptible to the increasing CO_2 effects, mainly due to the compensatory effects of increasing LAI and reduced transpiration at leaf level. Our results from model simulations indicate when and where we expect to detect physiological CO_2 effects in in-situ flux measurements. Finally, we apply the statistical methods to quantify the increasing CO_2 effects on carbon and water flux measurements across the FLUXNET network. Overall, the model-based analyses along with the observational study focused on the detection and potential quantification of iCO_2 effects, are critical and provide robust assessments of how the system will continue to change as CO_2 continues to rise.