Geophysical Research Abstracts
Vol. 15, EGU2013-9613, 2013
EGU General Assembly 2013

A vegetation sensitivity approximation for gross primary production in water limited conditions.

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The most severe impact of climate change on vegetation growth and agriculture is likely to occur under water-limited conditions. Under such conditions the plants optimize the inward flux of CO_2 and the outward flux of water vapor (the transpiration) by regulating the size of the stomata openings. Higher temperature increases water loss through transpiration, forcing the plants to diminish the stomata openings, which decreases photosynthesis. This is counteracted by higher CO_2 concentration, which allows plants to maintain the inward flux of CO_2 through the smaller openings. These two counteracting effects, combined with the change in precipitation, determine the net change of biological productivity in a changed climate. Here, a vegetation sensitivity approximation (VSA) is introduced, in order to understand and estimate the combined effect of changed temperature, CO_2-concentration and precipitation on gross primary production (GPP) to first order. According to the VSA, we have:

$$GPP = \left(\frac{\rho_{CO_2 atm}}{\rho_0}\right)^{\nu} P$$

Here $\rho_{CO_2 atm}$ is the atmospheric CO_2 concentration, ρ_0 is the baseline for atmospheric CO_2 concentration, P is precipitation and ν is defined by:

$$\nu = 1 - \frac{s}{11°\mathrm{C}}$$

where s is the climate sensitivity i.e. the increase in temperature when atmospheric CO_2 is doubled.

The VSA is based on the physical laws of gas flux through the stomata openings, and is only valid under water-limited conditions. It assumes that the temperature depends logarithmically on the CO_2 concentration with a given climate sensitivity. Transpiration is assumed to be a constant fraction of precipitation, which is reasonable under water-limited conditions. The VSA is compared to simulations with the dynamic vegetation model LPJ. The agreement is reasonable, and the deviations can be understood by comparison with Köppen's definition of arid climate: in an arid climate growth increases more according to LPJ than according to the VSA, and in non-arid conditions the reverse is true. Both the VSA and the LPJ simulations generally show increased growth with increasing CO_2 levels and the resulting temperature increase, assuming precipitation to be unchanged. Thus, for constant precipitation the negative temperature effect is more than compensated by the positive effect of CO_2.