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# Climate impacts of including plant-physiological $CO_2$ effects in regional climate models

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Many countries rely on regional climate model (RCM) simulations to quantify the projected impacts of climate change and design their national adaptation plans. The accuracy and reliability of RCM simulations is thus of fundamental importance and, in particular, it is crucial to include all relevant climate processes in RCMs. One of the processes not considered in most RCMs is the response of plants to elevated atmospheric $CO_2$ concentrations (the plant physiological $CO_2$ effect); a process which is however included in most global climate models (GCMs). Here we show that due to this missing process, RCMs underestimate the future increase of extreme temperatures compared to GCMs.

The plant physiological $CO_2$ effect takes into account that at higher $CO_2$ concentrations plants increase their water use efficiency, i.e. the fraction of $CO_2$ uptake to transpiration. As a consequence, plants reduce the openings of their leaf stomata at elevated $CO_2$ concentrations. This causes a reduction of plant transpiration, resulting in a decrease of latent heat flux and an increase of sensible heat flux. Ultimately, the plant physiological $CO_2$ effect can thus alter near-surface air temperatures. Using a state-of-the-art regional climate model (COSMO-CLM$^2$), we perform two model simulations: one that includes the plant physiological $CO_2$ effect and one where plants are insensitive to the atmospheric $CO_2$ increase. The simulations cover the European domain and the time span 1971-2099. In the simulation that includes the plant physiological $CO_2$ effect, evapotranspiration in central and northern Europe at the end of the $21^{st}$ century is significantly lower than in the simulation with insensitive plants (calculated as changes with respect to 1971-2000). In contrast, the evapotranspiration difference between both simulations is small in southern Europe, suggesting that other factors, such as soil moisture limitations, prevent a strong impact of the plant physiological $CO_2$ effect on evapotranspiration in this region. The results obtained with COSMO-CLM$^2$ are in line with the fact that RCMs from the EURO-CORDEX multi-model ensemble also exhibit lower evapotranspiration compared to GCMs in central and northern Europe at the end of the $21^{st}$ century (with respect to 1971-2000). Additionally, the results from COSMO-CLM$^2$ agree very well with estimations of the plant physiological $CO_2$ effect from dedicated CMIP5 experiments.

Including the plant physiological $CO_2$ effects in COSMO-CLM$^2$ also affects near-surface air temperatures. In central and northern Europe, the annual maximum temperature (TXx) is about 1 K higher in the COSMO-CLM$^2$ simulation with plant physiological $CO_2$ effects compared to the simulation with insensitive plants at the end of the $21^{st}$ century. This result can partially explain the discrepancy between the TXx evolution in GCMs and RCMs in central and northern Europe where at the end of the $21^{st}$ century GCMs exhibit a TXx increase that is about 2 K higher than the TXx increase in RCMs. According to the COSMO-CLM$^2$ simulations, the plant physiological $CO_2$ effect accounts for about 50 % of the TXx difference between GCMs and RCMs. Neglecting the plant physiological $CO_2$ effect can thus result in a substantial underestimation of future temperature increases in RCMs.