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GCM characteristics explain the majority of uncertainty in simulated future terrestrial carbon balance

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The response of the terrestrial carbon cycle to climate change constitutes a considerable part of the uncertainty surrounding climate change. One of the largest sources of this uncertainty is the heterogeneity of the predictions of future climate made by different climate models (general circulation models, GCMs). Not only do GCMs differ in their climate sensitivities and in regional distributions of changes in temperature, precipitation and radiation, they also differ markedly in simulated natural variability and climate extremes.

To investigate the role of climate variations in the uncertainties induced by differences between climate models we forced the detailed individual based ecosystem model LPJ-GUESS with outputs from four CMIP3 climate models under three SRES CO_2 concentration ($[CO_2]$) pathways. Based on results from the ecosystem model, we parameterized a statistical emulator of the global carbon cycle including only global temperature and $[CO_2]$ as the independent variables, scaled by parameters representing natural variability and regionality (α) and the land-to-global warming amplification (γ). Using singular value decomposition of simulated sea surface temperatures, a main driver of inter-annual variability in the climate system, we investigated the dominant patterns of variability and the resulting spatial carbon cycle patterns resulting from applying the four GCMs.

We find that the uptake of carbon differs more between climate models than between different $[CO_2]$ pathways. By sampling the parameters of the carbon cycle emulator we create 60 “artificial” climate models. Applying the emulator with these 60 parameterizations plus the original four GCMs under three $[CO_2]$ pathways (based on the SRES A2, A1B and B1 emission scenarios) resulted in a total of 192 simulations. We applied ANOVA to estimate how much of the variability in the simulated total carbon pool at year 2099 that can be explained by each factor, emission scenario, α and γ. The discrepancies in climate model natural variability, dominated by differences in El Niño-Southern Oscillation (ENSO) strength (α), explain 83% of the carbon balance uncertainties in our results (Figure 1).

Recent studies applying remote sensing and modeling to estimate past decades' NPP variability suggest that large-scale droughts are likely to have had an important and possibly dominant causal role in the NPP variations. Similarly, our results suggest that improved simulation of ENSO and low latitude precipitation patterns are important targets for narrowing the uncertainties in future climate change projections using ESMs or GCM-driven ecosystem impact models.