Nonlinear Interactions between Climate and Atmospheric Carbon Dioxide Drivers of Terrestrial and Marine Carbon Cycle Changes from 1850 to 2300

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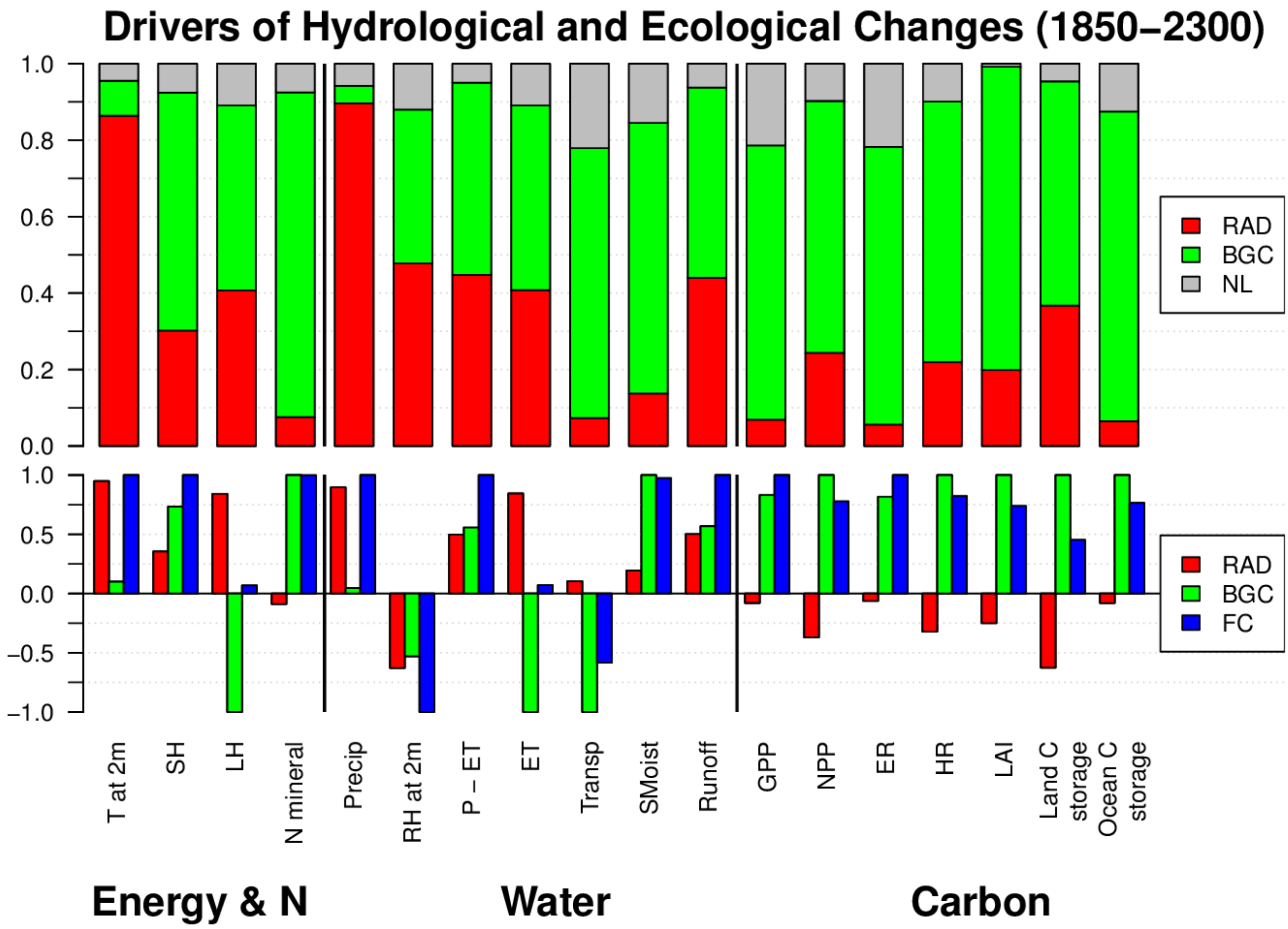
Quantifying feedbacks between the global carbon cycle and Earth's climate system is important for predicting future atmospheric CO_2 levels and informing carbon management and energy policies. We applied a feedback analysis framework to three sets of Historical (1850-2005), Representative Concentration Pathway 8.5 (2006-2100), and its extension (2101-2300) simulations from the Community Earth System Model version 1.0 (CESM1(BGC)) to quantify drivers of terrestrial and ocean responses of carbon uptake. In the biogeochemically coupled simulation (BGC), the effects of CO_2 fertilization and nitrogen deposition influenced marine and terrestrial carbon cycling. In the radiatively coupled simulation (RAD), the effects of rising temperature and circulation changes due to radiative forcing from CO_2, other greenhouse gases, and aerosols were the sole drivers of carbon cycle changes. In the third, fully coupled simulation (FC), both the biogeochemical and radiative coupling effects acted simultaneously. We found that climate-carbon sensitivities derived from RAD simulations produced a net ocean carbon storage climate sensitivity that was weaker and a net land carbon storage climate sensitivity that was stronger than those diagnosed from the FC and BGC simulations. For the ocean, this nonlinearity was associated with warming-induced weakening of ocean circulation and mixing that limited exchange of dissolved inorganic carbon between surface and deeper water masses. For the land, this nonlinearity was associated with strong gains in gross primary production in the FC simulation, driven by enhancements in the hydrological cycle and increased nutrient availability. We developed and applied a nonlinearity metric to rank model responses and driver variables. The climate-carbon cycle feedback gain at 2300 was 42% higher when estimated from climate-carbon sensitivities derived from the difference between FC and BGC than when derived from RAD. These differences are important to quantify and understand because different model intercomparison efforts have used different approaches to compute feedbacks, complicating intercomparison of ESMs over time. Underestimating the climate-carbon cycle feedback gain would result in allowable emissions estimates that would be too low to meet climate change targets. We further explored the degree to which these nonlinearities affect climate-carbon cycle feedback gain estimates in CMIP5 models at year 2100.

Keywords: carbon cycle, feedbacks, Earth system model


Drivers of Hydrological and Ecological Changes (1850–2300)
RAD
BGC
NL
RAD
BGC
FC
T at 2m
SH
LH
N mineral
Precip
RH at 2m
P – ET
ET
Transp
SMoist
Runoff
GPP
NPP
ER
HR
LAI
Land C storage
Ocean C storage
Energy & N
Water
Carbon