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Diagnosing turnover times of carbon in terrestrial ecosystems to address global climate co-variability and for model evaluation

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The response of the global terrestrial carbon cycle to climate change and the associated climate-carbon feedback has been shown to be highly uncertain. Ultimately this response depends on how carbon assimilation by vegetation changes relatively to the effective mean turnover time of carbon in vegetation and soils. Consequently, these turnover times of carbon are expected to depend on vegetation longevity and relative allocation to woody and non-woody biomass, and to litter and soil organic matter decomposition rates, which depend on climate variables, but also soil properties, biological activity and chemical composition of the litter. Data oriented estimates of whole ecosystem carbon turnover rates (τ) are based on global datasets of carbon stocks and fluxes and used to diagnose the co-variability of τ with climate. The overall mean global carbon turnover time estimated is 23 years (with 95% confidence intervals between 19 and 30 years), showing a strong spatial variability ranging from 15 years in equatorial regions to 255 years at latitudes north of 75ºN. This latitudinal pattern reflects the expected dependencies of metabolic activity and ecosystem dynamics to temperature. However, a strong local correlation of τ with mean annual precipitation patterns is at least as prevalent as the expected effect of temperature on the global patterns of τ. The comparing between observation-based estimates of τ with current state-of-the-art Earth system models shows a consistent latitudinal pattern but a significant underestimation bias of $\sim$36% globally. Models consistently show a stronger association of τ to temperature and do not reproduce the observed association to mean annual precipitation in different latitudinal bands. A further breakdown of τ focusing on forest background mortality also shows contrasting regional patterns to those of global vegetation models, suggesting that the treatment of plant mortality may be overly simplistic in different model formulations. Despite the challenges in underpinning the exact dynamics behind the observed relationships these findings highlight the relevance of the hydrological cycle in controlling the mean turnover times of carbon in terrestrial ecosystems. Overall we acknowledge that carbon turnover times are an emergent property that translates different aspects of ecosystem dynamics, which enable diagnosing ecosystem functioning as well as evaluating model behavior.