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Age and transit time distributions in nonlinear non-autonomous carbon cycle models

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Two main concepts help as diagnostics of the global carbon cycle, the age of the mass of carbon in a reservoir at a given time, and the age of the mass in the output flux from a reservoir system at a given time. These concepts, namely system age and transit time, are very useful metrics to compare models among each other, contrast observations against models, and make useful inferences about the global carbon cycle. However, there is confusion on the application of these concepts to applied problems, and for many applications, there were not yet explicit formulas for their computation. In this contribution, we will present new mathematical formulas for the computation of system age and transit time distributions for linear and non-linear systems as well as systems out of steady-state. We applied these formulas to estimate ages and transit times of carbon in a simple nonlinear non-autonomous global carbon model and other models of the terrestrial carbon cycle. First, we found that for terrestrial ecosystems in equilibrium, the age of stored carbon is much older than the age of the carbon that is exchanged with the atmosphere (ages $\ll$ transit times). Second, we calculated equilibrium and perturbed age distributions of carbon reservoirs as a result of fossil fuel combustion. Assuming fossil-fuel derived carbon is new to the system, we observed an important decline in the mean age of atmospheric, terrestrial, and surface ocean carbon up to the year 2300, when the mean age declines significantly compared to pre-industrial levels. Our transit time calculations showed that under a business-as-usual C emission scenario, it takes progressively longer to remove fossil-fuel derived carbon from the atmosphere-biosphere system.