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Global distribution of carbon turnover times in terrestrial ecosystems

Nuno Carvalhais (1,2), Matthias Forkel (1), Myroslava Khomik (1,3), Jessica Bellarby (4,5), Martin Jung (1), Mirco Migliavacca (1,6), Mingquan Mu (7), Sassan Saatchi (8), Maurizio Santoro (9), Martin Thurner (1,10), Ulrich Weber (1), Bernhard Ahrens (1), Christian Beer (1,10), Alessandro Cescatti (11), James T. Randerson (7), and Markus Reichstein (1)

(1) Max Planck Institute for Biogeochemistry, Jena, Germany (ncarval@bgc-jena.mpg.de), (2) Departamento de Ciências e Engenharia do Ambiente, DCEA, Faculdade de Ciências e Tecnologia, FCT, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal, (3) School of Geography and Earth Sciences, McMaster University, Hamilton, Ontario, L8S 4K1, Canada, (4) Institute of Biological and Environmental Sciences, School of Biological Sciences, University of Aberdeen, Aberdeen, AB24 3UU, UK, (5) Lancaster Environment Centre, Lancaster University, Bailrigg, Lancaster, LA1 4YQ, UK, (6) Remote Sensing of Environmental Dynamics Lab, DISAT, University of Milano-Bicocca, Piazza della Scienza 1, Milan, Italy, (7) Department of Earth System Science, University of California Irvine, Irvine, CA 92697, USA, (8) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA, (9) Gamma Remote Sensing, Worbstrasse 225, 3073 Gümligen, Switzerland, (10) Department of Applied Environmental Science and Bolin Centre for Climate Research, Stockholm University, Svante Arrhenius väg 8, 10691 Stockholm, Sweden, (11) European Commission, Joint Research Centre, Institute for Environment and Sustainability, Climate Change Risk Management Unit, Ispra, VA, Italy

The response of the carbon cycle in terrestrial ecosystems to climate variability remains one of the largest uncertainties affecting future projections of climate change. This feedback between the terrestrial carbon cycle and climate is partly determined by the response of carbon uptake and by changes in the residence time of carbon in land ecosystems, which depend on climate, soil, and vegetation type. Thus, it is of foremost importance to quantify the turnover times of carbon in terrestrial ecosystems and its spatial co-variability with climate.

Here, we develop a global, spatially explicit and observation-based assessment of whole-ecosystem carbon turnover times (τ) to investigate its co-variation with climate at global scale. Assuming a balance between uptake (gross primary production, GPP) and emission fluxes, τ can be defined as the ratio between the total stock (C_total) and the output or input fluxes (GPP). The estimation of vegetation (C_veg) stocks relies on new remote sensing-based estimates from Saatchi et al (2011) and Thurner et al (2014), while soil carbon stocks (C_soil) are estimated based on state of the art global (Harmonized World Soil Database) and regional (Northern Circumpolar Soil Carbon Database) datasets. The uptake flux estimates are based on global observation-based fields of GPP (Jung et al., 2011).

Globally, we find an overall mean global carbon turnover time of 23^{+7}_{-4} years (95% confidence interval). A strong spatial variability globally is also observed, from shorter residence times in equatorial regions to longer periods at latitudes north of 75ºN (mean τ of 15 and 255 years, respectively). The observed latitudinal pattern reflect the clear dependencies on temperature, showing increases from the equator to the poles, which is consistent with our current understanding of temperature controls on ecosystem dynamics. However, long turnover times are also observed in semi-arid and forest-herbaceous transition regions. Furthermore, based on a local correlation analysis, our results reveal a similarly strong association between τ and precipitation.

A further analysis of carbon turnover times as simulated by state-of-the-art coupled climate carbon-cycle models from the CMIP5 experiments reveals wide variations between models and a tendency to underestimate the global τ by 36%. The latitudinal patterns correlate significantly with the observation-based patterns. However, the models show stronger associations between τ and temperature than the observation-based estimates. In general, the stronger relationship between τ and precipitation is not reproduced and the modeled turnover times are significantly faster in many semi-arid regions. Ultimately, these results suggest a strong role of the hydrological cycle in the carbon cycle-climate interactions, which is not currently reproduced by Earth system models.