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The major axes of terrestrial ecosystem functions derived from ecosystem scale flux observations

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Understanding the coordination of ecosystem functions across global biomes is still a critical challenge in ecology to better predict biosphere response to environmental changes and for developing indicators of ecosystem multifunctionality. Theories such as the leaf economics spectrum and the global spectrum of plant forms and function showed that several plant and organs traits are coordinated in a few key dimensions representing different ecological strategies However, the main axes of variation of ecosystem-scale functions are still largely unknown.

In this contribution, we first derived a set of ecosystem functions from a dataset of surface gas exchange measurements across major terrestrial biomes. Second, we identify the most important axes of variation of ecosystem functions. Third, we identify the variables that explain the axes of variation. Finally, we analyze the extent to which two state-of-the-art land surface models reproduce the key axes of ecosystem functions.

To do so, we used data of carbon, water, and energy exchange for 203 sites (1484 site-years) from global surface flux datasets. Moreover, we compile site information on canopy-scale measurements of foliar chemistry (Nitrogen concentration), vegetation structural variables (maximum leaf area index, aboveground biomass, and vegetation height), and mean climate data at the sites.

We find evidence that three key axes capture the variability of ecosystem functions (71.8%). The first dimension represents maximum ecosystem productivity, which is explained primarily by vegetation structure, followed by mean climate. The second axis represents the water-use strategies driven by vegetation height and climate. The third dimension reflects the ecosystem carbon-use efficiency; it is controlled by vegetation structure but shows a gradient related to aridity.

The first axis of the spectrum is well captured by ecosystem models, while the second and third axes are poorly reproduced. As a result, the ecosystem functional space that the models can simulate tends to be smaller than the observations'. We assumed that the limited variability of the model output points to the uncertain implementation of plant hydraulics in land surface models. This known key limitation explains the differences between observations and models in the water use strategy axis. Concerning the carbon use strategy axis, one limitation is that models lack flexibility in representing the response of respiration rates and carbon-use efficiency to climate,

nutrients, disturbances, and substrate availability (including biomass and stand age, which relate to ecosystem management).

The concept of the key axes of ecosystem functions could be used as an indicator of ecosystem health and multifunctionality, and for the development of land surface models, which might help improve the predictability of the terrestrial carbon and water cycle in response to climate and environmental changes.

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