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A new theoretical approach to terrestrial ecosystem science based on multiscale observations and eco-evolutionary optimality principles

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Ecosystem science focuses on biophysical interactions of organisms and their abiotic environment, and comprises vital aspects of Earth system function such as the controls of carbon, water and energy exchanges between ecosystems and the atmosphere. Global numerical models of these processes have proliferated, and have been incorporated as standard components of Earth system models whose ambitious goal is to predict the coupled behaviour of the oceans, atmosphere and land on time scales from minutes to millennia. Unfortunately, however, the performance of most current terrestrial ecosystem models is highly unsatisfactory. Models typically fail the most basic observational benchmarks, and diverge greatly from one another when called upon to predict the response of ecosystem function and composition to environmental changes beyond the narrow range for which they were developed. This situation seems to have arisen for two inter-related reasons. First, general principles underlying many basic terrestrial biogeochemical processes have been neither clearly formulated nor adequately tested. Second, extensive observational data sets that could be used to test process formulations have become available only quite recently, long postdating the emergence of the current modelling paradigm. But the situation has changed now and ecosystem science needs to change too, to reflect both recent theoretical advances and the vast increase in the availability of relevant data sets at scales from the leaf to the globe.

This presentation will outline an emerging mathematical theory that links biophysical plant and ecosystem processes through testable hypotheses derived from the principle of optimization by natural selection. The development and testing of this theory has depended on the availability of extensive data sets on climate, leaf traits (including δ13C measurements), and ecosystem properties including green vegetation cover and land-atmosphere CO_2 fluxes. Achievements to date include unified explanations for observed climate and elevation effects on leaf CO_2 drawdown (ci:c¬a¬ ratio) and photosynthetic capacity (Vcmax), growth temperature effects on the Jmax:Vcmax ratio, the adaptive nature of acclimation to enhanced CO_2 concentration, the controls of leaf versus sapwood respiration, the controls of leaf N content (Narea), the relative constancy of the light use efficiency of gross primary production, and the relative conservatism of leaf dark respiration with climate. These findings call into question many assumptions in supposed "state-of-the-art" terrestrial ecosystem models, and provide a foundation for next-generation global ecosystem models that will rest on a greatly strengthened theoretical and empirical basis.