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New approaches to modelling the terrestrial biosphere and its response to change

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Global changes alter the shape and functioning of the terrestrial biosphere, with consequences for climate feedbacks and biogeochemical cycles. Quite certainly, the terrestrial biosphere will adapt to these changes to some extent. Ecophysiological processes will acclimatize to the changing conditions, plants will adapt, and changes in the species composition will result in adjustments at the ecosystem level. Current approaches to modelling vegetation dynamics are typically based on semi-empirical relationships to describe ecophysiological functioning and represent vegetation composition by only a few plant functional types. When these approaches are used in scenarios of future global warming, some predict drastic changes in vegetation, for instance a dramatic dieback of the Amazon rainforest. But are current approaches able to adequately capture the adaptive nature of the terrestrial biosphere?

Here I present an overview of three complementary approaches that can capture adaptive dynamics of the biosphere, by (i) using optimality assumptions such as maximizing productivity; by (ii) incorporating a diverse representation of biospheric dynamics; and by (iii) a thermodynamic description of ecosystem functioning which allows for the implementation of thermodynamics-based optimality principles. The first approach assumes that present-day vegetation evolves and adapts in a way to make best use of its environmental resources. This assumption can then be applied to vegetation models to infer certain optimal characteristics, such as stomatal conductance or rooting depth, from the maximization of a goal function. Under altered climatic conditions, the optimum values of vegetation characteristics would likely change. The implementation of optimality would then capture adaptation as the process resulting in optimization. Potential issues with this approach are that it is not clear which property or flux should be maximized (i.e. the choice of the goal function) and on which time scale optimality should be assumed. The second approach can capture the whole range of possible plant functioning, which combined with community assembly rules yields a diverse description of biospheric dynamics. This approach allows plants to be successful in many different ways and thus represents the functional diversity inherent in the terrestrial biosphere. The great power of this approach is that one can explicitly explore the emergent behavior of the dynamics, test for optimality approaches as well as temporal dynamics. Under altered climatic conditions, the assembly of communities would likely change, thereby resulting in adaptation of ecosystems to altered conditions. However, potential obstacles to this approach include the choice of assembly rules as well as substantially increased computational demand. The third approach bases the functioning of the terrestrial biosphere on a solid, thermodynamic foundation. Thermodynamics is a powerful and fundamental theory of physics that describes the strength and direction of practically all Earth system processes. Such a thermodynamic description allows for the use of proposed thermodynamic optimality principles, such as Maximum Power Principle (MPP) or Maximum Entropy Production (MEP). The advantage of this approach is that it is much more general than the first approach, in fact it is so general that it can be used for complex processes that are purely physical in their nature. The disadvantage of this approach at this time is that it still requires substantial work to develop a full, thermodynamic description of Earth system processes to adequately describe the fluxes of energy, matter, momentum and entropy across the biosphere-Earth system interface and to describe plant ecophysiological processes in thermodynamic terms.

Each of the three approaches is illustrated with examples from modelling studies and is discussed in terms of how these could be used to improve the representation of biospheric dynamics in global Earth system models. The talk closes with a summary and perspective.