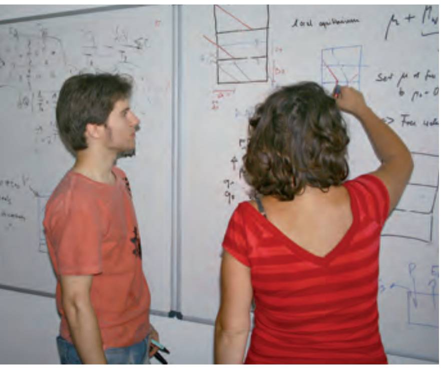


Max Planck Research Group

Biospheric Theory and Modelling

We develop and use theoretical approaches and numerical simulation models to investigate the role of the biota in driving the global geochemical cycles within the Earth system. We use these models to reproduce and explain the observed geographic variation of terrestrial vegetation, fluxes of energy, water, carbon, and other elements for the present-day, Earth's past evolution and evaluate the consequences of human actions.

Matter mixes, water flows downhill and wood burns into ashes. In the absence of other processes, sooner or later all matter would be uniformly mixed. Water would collect in the world's oceans, mountains would be eroded down to the seafloor, and wood would be burnt to ashes. These processes would transform the distribution of geochemical elements into a „dead" Earth state, with no gradients present to drive fluxes that result in global cycles of geochemical elements and no free energy would be available to "run" life.

These seemingly trivial observations highlight an underlying general direction into which any process in the Earth system evolves in time. The examples describe processes that cannot be undone, or, technically speaking, they are irreversible. This direction is understood and quantified in general terms using the fundamental physical theory of thermodynamics, and applies to all geochemical processes and global cycles of Earth as well as life itself.

What is it about the planet Earth which allows it to be maintained so far away from the final, „dead" state of thermodynamic equilibrium? Which processes perform the physical and chemical work that separates matter, moves water uphill, forms mountains, and produces wood out of ashes? What role does life and its inherent diversity play in driving the Earth's state far from equilibrium? And when we consider human activities and associated global change, do these bring the Earth system closer to or further away from the „dead" state of thermodynamic equilibrium?

The research of the "Biospheric Theory and Modelling" group addresses these questions based on a holistic perspective of how the thermodynamic Earth system works. The research

Portrait of the Group Leader

Axel Kleidon studied physics, mathematics and meteorology at the University of Hamburg and Purdue University. He received his Ph.D. in meteorology from the University of Hamburg. After his PostDoc at Stanford University he joined the faculty of the University of Maryland. Since 2006 he leads a Max Planck Research Group. Research interests: atmosphere-biosphere interactions, biodiversity, vegetation modelling, non-equilibrium thermodynamics, Gaia hypothesis, Earth system evolution.

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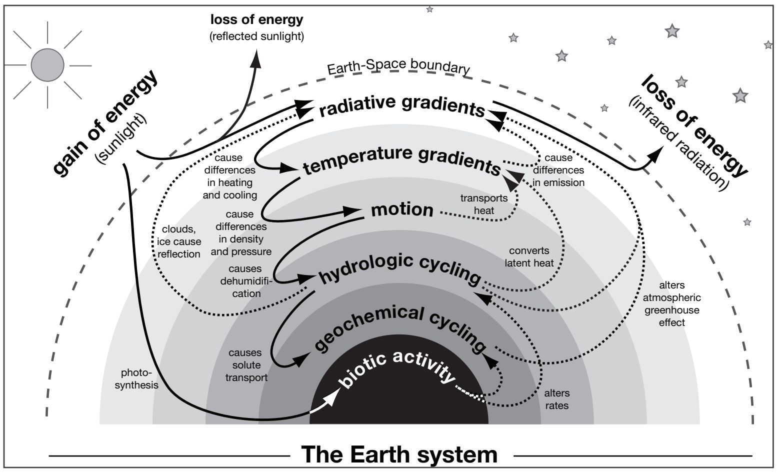
focuses primarily on (i) developing the thermodynamic foundation of Earth system processes, their couplings and interactions, (ii) a detailed understanding of the processes that exchange, transform and transport energy and geochemical elements on land and (iii) explaining the functioning of a diverse, terrestrial biosphere and how it interacts with the prevailing geochemical conditions.



Schematic diagram of the chain of energy and mass conversions that drive the Earth system away from a state of thermodynamic equilibrium. Radiative gradients generated by energy exchange with space are transformed into temperature gradients, motion, hydrologic and geochemical cycling, and these interact with biotic activity.

Focus 1. Thermodynamics of the Earth System

We describe Earth system processes in purely thermodynamic terms and implement these formulations into analytical and numerical models. Processes related to biogeochemical cycles are formulated as functions of thermodynamic gradients that result in fluxes depleting those gradients. These models are used to quantify the thermodynamic nature of geochemical processes and their sensitivity to alterations, for example by various biotic effects, inter alia human modifications such as deforestation and the extraction of wind power to generate electricity. We test the applicability of the proposed principle of Maximum Entropy Production to a variety of complex Earth system processes. This principle states that sufficiently complex processes generate and dissipate as much free energy as possible. We use these approaches to improve model formulations and to evaluate how the reconstructed patterns of Earth-life co-evolution relate to thermodynamic trends. This research focus contributes to the Helmholtz Alliance on "Planetary Evolution and Life".

Focus 2. Land Surface Dynamics

We develop numerical models to simulate the dynamics of the land surface, continental transport processes, geochemical cycling on land, and the sensitivity of the processes involved to biotic activity. Processes such as the weathering of rocks, soil formation, and erosion of soils impose constraints on biotic activity, biogeochemical cycling, and feedbacks to the Earth system on a variety of time scales. The intensity of the weathering of silicate rocks, for instance, strongly shapes the geologic carbon cycle, which in turn determines atmospheric carbon dioxide concentrations at time scales of millions of years. Closely linked to the weathering of primary material is the availability of phosphorus, which is believed to be a primary limiting nutrient in tropical ecosystems. Hence, processes operating at time scales of millions of years can play a critical role in shaping the short-term response of the biota and land surface fluxes to global change. Our simulation models allow us to quantify this highly relevant aspect for the interpretation of Earth system history as well as the impacts of anticipated future global changes.

Focus 3. The Diverse Biosphere

We work on and apply novel approaches to explain patterns and function of the diverse biosphere. Our simulation model allows us to analyze current patterns of the terrestrial biosphere, such as the distribution of vegetation biodiversity, relative abundance distributions of species within communities, functional traits of vegetation and the extent to which climate is reflected in these. By explicitly modelling population and diversity dynamics of the vegetative cover, we are able to evaluate the effect of diversity on land surface fluxes and the extent to which the vegetative cover can adapt to a changing climate. We evaluate different hypotheses that formulate causes, consequences and patterns of biodiversity and relate emergent biogeochemical fluxes and vegetation structure to complex systems theories and optimization approaches.