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Can’t we just keep it simple? Using thermodynamic limits to formulate simple models and to get robust predictions of the complex Earth system

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The Earth is, undoubtedly, a vastly complex system that is shaped by a range of processes, from solar radiation to planetary motion, geochemical cycling, biotic and human activity, all interacting across a range of time scales to shape the emergent state of the system. The common approach to deal with modelling parts of or the whole Earth system is to build increasingly more comprehensive models, with higher resolutions, a greater range of processes, and a greater number of interactions being represented. Yet, this also yields increasingly incomprehensible models in which the underlying assumptions in the model parameterizations are obscured.

I present an alternative approach to model the complex Earth system that focuses on fundamental physical constraints and that allows for insights from simple, back-of-the-envelope calculations. This approach is based on describing the Earth as a thermodynamic system with dynamics that are driven by energy conversions, and in which its complexity is dealt with by the assumption that the dynamics operate at their thermodynamic limit. It requires us to think of Earth system processes in terms of the energy that they convert, the origin of this energy, the interactions that result from the energy conversion, and how these factors shape the resulting thermodynamic limit. The behavior of the complex Earth system then becomes predictable by relatively simple means, not because we deal with a simple system, but because it is so complex that it is ultimately constrained by fundamental thermodynamic limits that can be derived by comparably simple means.

I illustrate this approach with three examples, dealing with the hydrologic sensitivity to global warming, the surface energy balance partitioning on land at the diurnal scale, and the limits to wind power as renewable energy. Each example shows that the approach matches observations or complex climate models very well, highlighting that this approach provides a simple alternative to derive the expected behavior of the Earth system and its response to change from first principles.

This approach can provide a few key insights on essential components for model building that appear to be rather general. This starts with a thermodynamic formulation of processes in terms of the energy that these convert as this sets the basis for formulating fundamental limits. Interactions then play a central role in shaping these limits as well as the formulation of the system boundary. In addition to providing insights into model building, the approach can provide a baseline reference for setting up hypotheses that can supplement the interpretation of observations and numerical simulations with comprehensive Earth system models.