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From conceptual to complex earth system models: why are models so linear?

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The evolution of the Earth's climate from the past to the future is explored by a hierarchy of models ranging from conceptual models to full-complexity, high-resolution Earth System Models (ESMs) (Claussen et al., 2002). The strength of conceptual models lies in the clarity of representing the concept of interactions between different climate processes, while ESMs offer greater realism when it comes to spatial or temporal detail. Intermediate complexity models are somewhere in between, they are able to provide a big picture for long timescales. A common pattern throughout the model hierarchy, except for conceptual models illustrating multiple steady states, is often linearity of model responses to external forcing. This linearity can be visible in transient experiments, but also in equilibrium simulations. The question arises: is this linearity an artefact of our models, or is it reflective of reality?

In most cases, the linear response is likely representative of reality. As an example, we will focus on the linearity of land-related processes, such as climate-carbon feedbacks and permafrost-hydrology interactions. Permafrost systems have thresholds at 0°C, leading to nonlinearities at the local scale, but the combined response at large spatial scales tends to be more linear. However, nonlinear and abrupt changes are evident in geological records. For instance, the abrupt onset of the Bölling/Alleröd warming about 14.8 thousand years ago indicates that nonlinear changes on large spatial scales are indeed a real, albeit very rare, phenomenon. We will discuss possible reasons for the predominant linearity of the models and explore whether high-resolution models might show more nonlinear responses than coarse-grid models.

Reference:

Claussen, M., Mysak, L., Weaver, A. et al. Earth system models of intermediate complexity: closing the gap in the spectrum of climate system models. Climate Dynamics 18, 579–586 (2002). https://doi.org/10.1007/s00382-001-0200-1