Earth-System Models of Intermediate Complexity

Introductory Remarks

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Background and Motivation

Investigating the dynamic behavior of the Earth system remains a “grand challenge” for the scientific community. It is motivated by our limited knowledge about the consequences of large-scale perturbations of the Earth system by human activities, such as fossil-fuel combustion or the fragmentation of terrestrial vegetation cover. Will the system behave resilient with respect to such disturbances, or could it be driven towards qualitatively new modes of planetary operation?

This question cannot be answered, however, without prior analysis of how the unperturbed Earth system behaves and evolves in the absence of human influence. Such an analysis should, for example, provide answers to questions concerning the amplification of Milankovich forcing to glaciation episodes or the mechanisms behind the Dansgaard-Oeschger oscillations. But also more general questions may be addressed: Does life on Earth subsist due to an accidental and fragile balance between the abiotic world (the geosphere) and a biosphere that has emerged by chance? Or are there self-stabilizing feedback mechanisms at work as proposed by the GAIA theory? And, if the latter theory is valid, what is the role of humanity in GAIA’s universe?

Towards a Definition of the Earth System and Earth System Models

To our knowlegde, no generally accepted definition of the “Earth system” exists. As a starting point for further discussion, we therefore propose the following notation which has been put forward by Schellnhuber (1998) and Claussen (1998): The Earth system encompasses the natural environment, i.e. the climate system according to the definition by Peixoto and Oort (1992), or sometimes referred to as the ecosphere, and the anthroposphere. The climate system consists of the abiotic world, the geosphere, and the living world, the biosphere. Geosphere and biosphere are further divided into components such as the atmosphere, hydrosphere, etc., which interact via fluxes of momentum, energy, water, carbon, and other substances.

This workshop will focus on the natural dimension of the Earth system with the anthroposphere as prescribed boundary condition. However, an outline of Earth system analysis as well as some first steps towards (fully coupled) Earth system models will be presented. So far, only very simplified Earth system models exist for obvious reasons. While models of the climate system can be built upon the thermodynamic approach, this does no seem to be feasible for many components of the anthroposphere, in particular the psycho-social component.

Earth system models need to be globally comprehensive models, because the fluxes within the system are global (e.g. the hydrological cycle): changes in one region may well be caused by changes in a distant region. A currently open question is how much spatial (regional) resolution is required to appropriately capture processes with global significance. Clearly, Earth system models need not capture all aspects of interaction between the spheres at the regional scale - this is the realm of regionally integrated models.

Models of Intermediate Complexity

During the past decades marked progress has been achieved in modelling the separate elements of the geosphere and the biosphere, focusing on atmospheric and ocean circulation, and on land vegetation and ice-sheet dynamics. These developments have stimulated first attempts to put all separate pieces together, first in form of comprehensive coupled models of atmospheric and oceanic circulation, and eventually as so-called climate system models which include also biological and geochemical processes. One major limitation in the application of such comprehensive Earth system models arises from their high computational cost.

Due to these problems, simplified and computationally efficient models of the climate system are used for a variety of applications, in particular paleoclimate studies as well as climate change and climate impact projections. These models are spatially highly aggregated, for example, they represent atmosphere and ocean as two boxes, and they describe only a very limited number of processes and variables. The applicability of this class of model is limited not by computational cost, but by the lack of many important processes and feedbacks operating in the real world. Moreover, the sensitivity of these models to external forcing is often prescribed rather than computed independently (e.g. Houghton et al., 1997).

To bridge the gap, Earth System Models of Intermediate Complexity (EMICs) have been proposed. For the purposes of this workshop, we suggest to characterize these models in the following way: EMICs describe most of the processes implicit in comprehensive models, albeit in a more reduced, i.e. a more parameterized form. They explicitly simulate the interactions among several components of the climate system including biogeochemical cycles. On the other hand, EMICs are simple enough to allow for long-term climate simulations over several 10.000 years or a broad range of sensitivity experiments over several millennia. Similar to those of comprehensive models, but in contrast to simple models, the degrees of freedom of an EMIC exceed the number of adjustable parameters by several orders of magnitude. Tentatively, we may define an EMIC in terms of a three-dimensional vector: Integration, i.e. number of components of the Earth system explicitly described in the model, number of processes explicitly described, and detail of description of processes (See Figure 1).

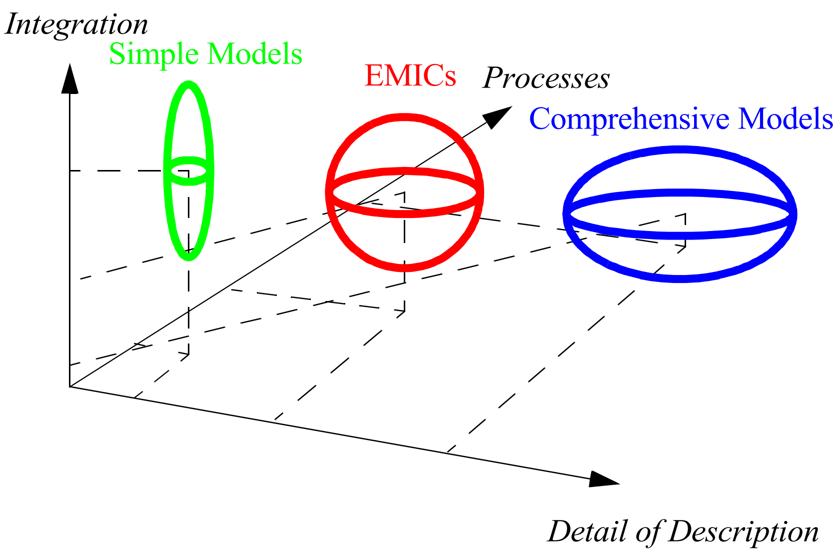

Figure 1: Tentative definition of EMICs

The way forward

Earth System analysis relies on a hierarchy of simulation models. Depending on the nature of questions asked and the pertinent time scales, there are, on the one extreme, zero-dimensional tutorial or conceptual models like those in the "Daisyworld" family. At the other extreme, three-dimensional comprehensive models, e.g. coupling atmospheric and oceanic circulation with explicit geography and high spatio-temporal resolution, are under development in several groups. Both types of models will be presented during the first day of the workshop.

During the IGBP Congress in Shonan Village, Japan, May 1999, it became more widely recognized that models of intermediate complexity could be very valuable in exploring the interactions between all components of the natural Earth system, and that the results could be a more realistic than those from conceptual models. Several other meetings have pointed at the potential that EMICs even might have for the policy guidance process, such as the IPCC. We therefore need to discuss EMIC development in a broader community now. As a starting point, we suggest to discuss the following points during the workshop:

- How far can we reduce a (notional) comprehensive Earth System model without losing the crucial feedbacks that govern the Earth systems dynamics?
- More specifically: which processes are crucial for the dynamic behaviour of the Earth system?
- Should all subcomponents of the coupled model maintain an "equal" level of complexity, or is it meaningful to couple, e.g., a comprehensive Dynamic Global Vegetation Model (DGVM) to an intermediate complexity Atmosphere General Circulation Model (AGCM)?
- Which types of data can be used to validate EMICs and are sufficient of these data available?

Finally, we would like to emphasise that it is not our goal to produce a single unified EMIC. Different developments have been and will be spawned that have different purposes. But it should be possible to define a minimal set of requirements that should be fulfilled by models to ensure their credibility in the light of today's knowledge about the Earth system - such a set might well be the outcome of our discussions in Potsdam.

Reference

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