



Earth System Models



Their use and reliability in past climate reconstructions and future predictions

What are Earth System Models?

Earth System Models are sets of equations describing processes within and between the atmosphere, ocean, cryosphere, and the terrestrial and marine biosphere. These underlying equations contain information about physical, chemical and biological mechanisms governing the rates of change of the elements of the Earth System. External drivers of the

system remain unaffected by climate change and include tectonically driven changes of the Earth System, volcanic eruptions and changes in the incoming solar energy. Models can be used to study climate at a particular time in Earth history or to portray the evolution of climate through time.

Why do we need models?

Models are the best tools available to test hypotheses about the factors causing climate change and to assess future Earth system developments. By changing the forcing (e.g., carbon dioxide concentration, orbital parameters, solar irradiance) one can study the direction and magnitude of the response, (e.g., temperature, precipitation, vegetation, ocean chemistry). By switching certain processes on and off in a model, one can disentangle the role of these processes in Global

Change. Output from model simulations can also provide information on specific parameters of the Earth System for which proxy-based reconstruction is not possible (e.g., air pressure). Furthermore, by integrating Earth System models and proxy-based reconstructions of past climate states it becomes possible to assess climate in a consistent way, even at locations for which no reconstructions exist.

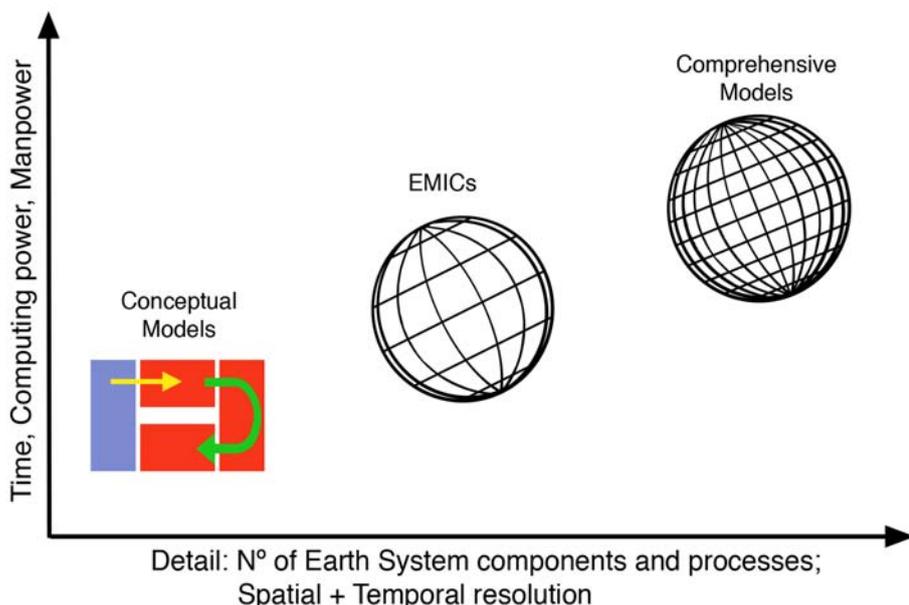
What types of models are there?

Models range from relatively simple to quite complex, differing in the level of detail and the aspects of the Earth System they include. The type of model used depends on the question being asked. At the one extreme are the relatively simple conceptual models,

such as box models, which can be run on an ordinary PC or can be calculated in an analytical form. They reveal only key processes of the Earth System (such as oceanic deep-water formation), and can be applied to studying the basic dynamic behavior of the Earth

System. This includes questions about abrupt climate change and feedback mechanisms. However, these models simplify the system to a large degree and cannot be used to describe complex features on Earth.

At the other extreme are comprehensive models, such as general circulation models (GCMs), which require super computers and can take months to produce a single climate prediction. These models include the explicit description of known processes (circulation, precipitation, ice sheet dynamics, etc.) using a 3-D grid of the Earth with a detailed representation of the atmosphere, ocean, and cryosphere. Typically, the individual boxes that make up the

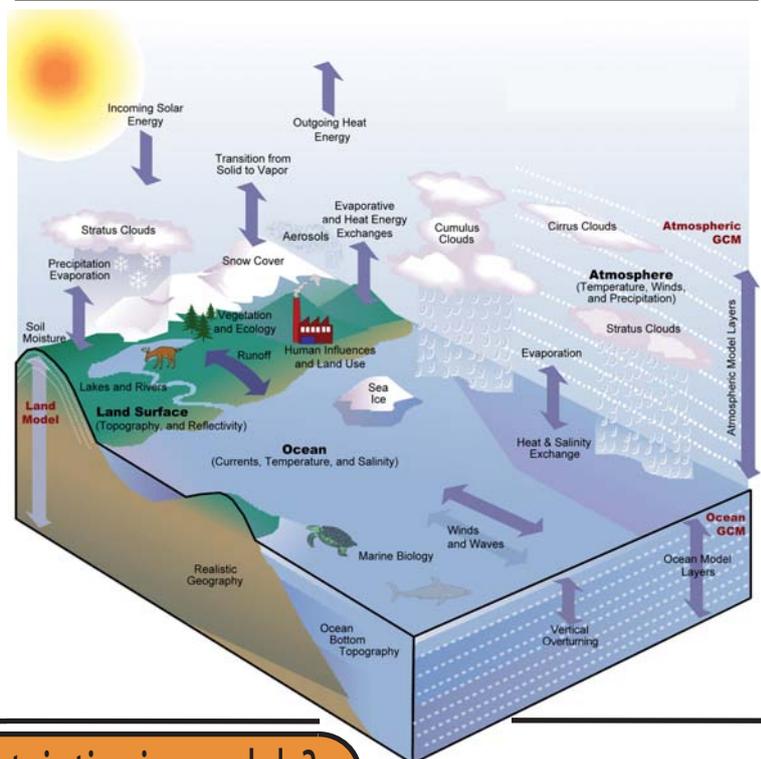


The time required and level of detail involved in each of the three model types.

grid are smaller than 500 km. The resulting simulations are used to describe a detailed response of the Earth System in such areas as seasonal climate prediction, simulations of past climates and predictions of future scenarios. The substantial computer resources required here can make it difficult to analyze all combinations of processes and parameter, particularly for long-term past climate evolution.

Between these two extremes are the models of intermediate complexity (EMICs), which do not require super computers and can therefore be run often, test multiple hypotheses, and simulate several thousand years of past climate evolution. They typically contain more processes than conceptual models (reducing some of the problems of over-simplifying a system) but less than comprehensive models (reducing processing time and providing manageable output). EMICs also often include Earth System components, such as continental ice sheet models, not currently included in Comprehensive Models. However, EMICs can lack some of the important features and do not have fine enough spatial resolution to simulate regional features.

Components of the climate system and the interactions among them, including the human component. All these components are included in a General Circulation Model. Figure from Karl, T.R. and Trenberth, K.E., 2003: Modern Global Climate Change, *Science*, **302**: 1719 - 1723.



What are the uncertainties in models?

Difficulties in building Earth system models arise from insufficient knowledge of physical, chemical and biological mechanisms involved in the climate system and from insufficient resolution of known processes. An inherent problem of climate is that it encompasses some degree of unpredictability, that is, predictions can only be made regarding the ranges of possible outcomes. Thus, although any one sequence of calculations might result in one particular prediction of climate state at the end of the experiment, such a prediction is just one possibility among many.

The range of uncertainty in possible outcomes can be explored by making a number of "repeat" runs, that is, model experiments which are identical to each other except for changes in initial state (ensemble predictions). Other methods focus not so much on the inherent internal variability but on the uncertainty contained in the rules that govern change. Such sensi-

tivity experiments can be extremely expensive in terms of time requirements on large computers. Another check on the reliability of predictions is a comparison between different models. If they disagree markedly, they cannot all be correct and a search for the reason of disagreement is indicated.

Model parameters are initially optimized for present climate conditions. If a model can simulate aspects of the instrumental record, then this is a measure of the model's accuracy. Models are also tested for how well they replicate present-day aspects of climate variability, such as the El Niño Southern Oscillation. However, the instrumental record covers only a small fraction of the possible range of climate variability. Therefore, comparison of modeled climate states with larger climate perturbations that occurred in the past, and can be reconstructed from geological archives, can provide a strong validation of a model.

Further Information

- Spencer R. Weart: Simple Models of Climate
www.aip.org/history/climate/simple.htm

- McGuffie, K., and A. Henderson-Sellers, A climate modelling primer, John Wiley & Sons, Chichester, 2005, 280 pp..

- Types of climate models
www.metoffice.gov.uk/research/hadleycentre/models/modeltypes.html

- Modelling the climate
www.climateprediction.net/science/model-intro.php

- Models 'key to climate forecasts'
<http://news.bbc.co.uk/1/hi/sci/tech/6320515.stm>